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NIGHT ATTACK WORKLOAD STEERING GROUP: SIMULATION AND HUMAN FACTORS SUBGROUP

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June 1982

Final Report for period 26 June 1980 - August 1981

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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This report documents the conclusions and recommendations of the Sub-Group for Simulation, Human Factors, and Research (SHFR), of the Night Attack Workload Steering Group. This is the last of a series of reviews and study reports which examined topics pertinent to night attack pilot workload measurement. Sub-Group products have included separate reviews of prior simulation studes, simulation facility capabilities, and workload metrics. Twenty current recommendations are documented herein which will create the (continued on next page)

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human factors/pilot workload data base needed to support short term LANTIRN needs as well as long term needs of the night attack system development community. Work recommended ranges from small, specific studies of supporting technology (such as terrain following algorithms and color displays) to large pilot-in-the-loop technology integration studies which require extensive supporting simulation equipment development. Each study addressed includes recommendations for organizational assignments and facility usage. In composite the SHFR recommendations provide a comprehensive roadmap for workload data development needed to support night attack system acquisition through the 1980s.

PREFACE

This evaluation of simulation and human factors research requirements was conducted for the Night Attack Workload Steering Group under the authority of Air Force Systems Command (AFSC) in response to a request by the Commander, Air Force Systems Command. This work was accomplished under Project No. 7184, Program Element 62202F, Task No. 718411 and Work Unit No. 71841145. This program was accomplished during the period of June 1980 to August 1981.

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SECTION I

INTRODUCTION

The Night Attack Workload Steering Group (NAWSG) was formed by Lt Gen Lawrence Skantze, Commander, Aeronautical Systems Division (ASD) on 13 June 1980 as a direct result of concern by General Alton D. Slay, Commander, Air Force Systems Command (AFSC) regarding pilot workload as a determining factor in tactical night attack effectivness. Events leading to this concern included Tactical Air Comand's (TAC) flight test results of the Fairchild Republic Corporation two-seat A-10 aircraft, as well as the Low Altitude Navigation and Targeting Infared for Night (LANTIRN) system presently under development.

The composition of the NAWSG was drawn from a broad range of units throughout the Air Force having interest in night attack systems.

The NAWSG was chaired by Col Robert F. Lopina, Deputy for Engineering at ASD, who established subgroups to address particular aspects of the problem, including existing and in process equipments, flight test and operational experience, and simulation and human factors.

This report documents the efforts of the Simulation, Human Factors and Research subgroup.

SECTION II

HISTORICAL OVERVIEW

The Simulation, Human Factors and Research (SHFR) Sub-Group was chartered to recommend studies, simulations and flight tests required to provide the technical data base to support near-term LANTIRN integration and the orderly long-term development of night attack technology. The Sub-Group's membership was comprised of representatives from the ASD engineering community, AFWAL, AFAMRL, The School of Aerospace Medicine, AFTEC, AFFTC, and HQ USAF. Numerous Sub-Group products have been published which deal with issues pertinent to near-term LANTIRN integration and operational workload assessment. Some of these are provided as appendices to this report, including: the results of a comprehensive survey of Government and industry simulation capbilities (Appendix A); surveys of pilot workload measurement techniques (Appendices B and C); a review of past studies performed in support of the night attack mission (appendix D); and a summary of general considerations for operational FMD applications (Appendix E).

The SHFR recommendations for simulation studies supporting near-term LANTIRN integration were forwarded to the LANTIRN, A-10, and F-16 System Program Office (SPOs) in October 1980. Key elements of the recommendations included: (1) development of mission scenarios for A-10/LANTIRN which could be used as standards for multiple studies; (2) performance of functional time line and analysis for integrated A-10 LANTIRN operations; (3) tailoring of the Conjoint Method of workload measurement for the LANTIRN mission; (4) real-time A-10/LANTIRN simulation using ASD's Crew Station Design Facility; and (5) computer simulation of the A-10/LANTIRN mission using Systems Analysis of Integrated Networks of Tasks (SAINT) to identify and iterate around performance chokepoints. Taken as a package, these recommendations constituted a systems approach to LANTIRN workload analysis. All recommendations were accepted by the SPOs, with an expansion of scope to include the F-16/LANTIRN integration. Most tasks are in various stages of completion. These efforts should provide a significant data base supporting the LANTIRN integration.

Significant additional study is required to address the scope of integration concerns identified by the Flight Test and Operational Experience Sub-Group. Simulation capabilities required to support this work range from part task systems currently available at existing facilities, to those requiring development of a full-scale tactical simulation complex requiring extensive simulation technology development many years in the future.

SECTION III

BASIS FOR RECOMMENDATIONS

The activities and products of each of the other subpanels of the Night Attack Workload Steering Group have provided an excellent data base from which substantiated recommendations may be developed to guide future simulation and human factors support efforts in the night attack technology arena. Each of the specific recommendations by the Human Factors and Simulation Subpanel draw upon this data base and are formulated against an additional background of expertise in state of the art simulation technology, human factors/biotechnology research, including workload assessment and systems modeling. Near-term recommendations are directed at solving the immediate problem of LANTIRN SPO support of simulation facilities, ASD Crew Station Design Facility (CSDF) development, SAINT model development and workload assessment efforts. Longer-term recommendations evolve from requirements that are not able to be fulfilled due to either lack of visible funding sources, long lead-times for development of supporting technologies, or priority considerations.

It must be emphasized that due to the evolutionary nature of technology and research in support of future night attack systems, the prioritization and time base suggested for conducting the various efforts represents a consolidated judgment at this point in time only. Results from both the planned CSDF and SAINT simulations may identify crucial aspects of equipment performance, operator workload or other elements that significantly impact the phasing and priorities listed here.

In those cases where the recommended research is beyond a particular organization's baseline program and funds required to perform the effort could be realistically projected, they are specified.

SECTION IV

RECOMMENDATION SUMMARY

Twenty specific recommendations have been defined by the SHFR Sub-Group for technology in support of LANTIRN and/or a generalized night attack capability. Each is comprehensively described in Section V of this report. A summary of all recommendations with associated schedules is provided on page 6.

The following studies are recommended for the near term (1981 to 1986) to enhance the integration/introduction of LANTIRN. Studies are grouped by priority.

1. HIGH PRIORITY - NEAR TERM

   a. Workload Metric Development/Application

   b. Workload Assessment under Degraded and Enhanced Modes - LANTIRN

   c. Situation Awareness and Target Acquisition with FLIR Imagery

   d. Terrain Following/Terrain Avoidance - Manual vs Automatic

   e. Radar Altimeter Integration

   f. Inertial Navigation System Integration

   g. Operational Training System Development

   h. FLIR Image Generation Technology

2. MEDIUM PRIORITY - NEAR TERM

   a. Head Up/Head Down Display Alternatives

   b. Interaction of Displayed Target Position with Sensor Field-of-View and Field-of-Regard

   c. Multi-Function Controls and Displays (MFCD)

   d. Color Display Integration

   e. Voice Warning System Integration

   f. FLIR Simulation Data Base Development

3. LOW PRIORITY - NEAR TERM

   Visual Accommodation for Cockpit vs HUD Information

The following studies are recommended for the far term (beyond 1986) to enhance night attack capabilities.

4. HIGH PRIORITY - FAR TERM

a. Workload Metric Development/Application (continuing)

b. Terrain Following/Terrain Avoidance - Manual vs Automatic (continuing)

c. Inertial Navigation System Integration (continuing)

d. Full Scale Tactical Simulation System Development

e. FLIR Image Generation Technology (continuing)

5. MEDIUM PRIORITY - FAR TERM

a. Head Up/Head Down Display Alternatives (Continuing)

b. Multi-Function Controls and Displays (MFCD) (continuing)

c. Color Display Integration (continuing)

d. Helmet-Mounted Sights and Displays

e. Voice Warning Systems Integration (continuing)

f. FLIR Simulation Data Base Development (Continuing)

6. LOW PRIORITY - FAR TERM

a. Visual Accommodation for Cockpit vs HUD Information (continuing)

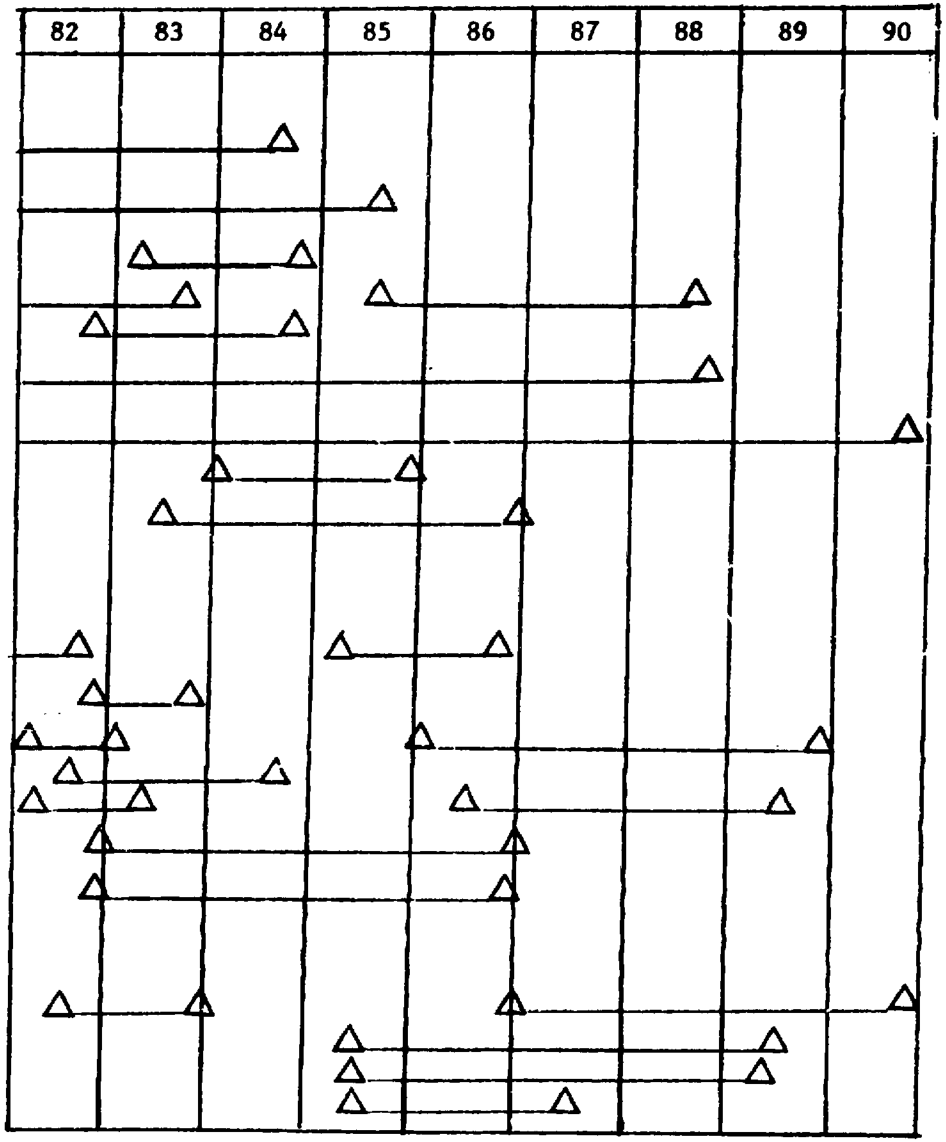
b. Correlated Sensor/Image Processing

c. Electronic Synthesized Displays

d. Voice Control System Integration

Studies above require simulation hardware/facility support levels ranging from basic existing facilities, to those of a fully integrated full mission simulation capability which does not exist and is not supported by the current state of the art. FLIR image generation poses the greatest obstacle to the integration of a full mission simulation capability. Much advanced development work is required to support the long track, low level, high fidelity FLIR imagery required to support workload assessment studies and operational training. Descriptions for each of the studies recommended above include a discussion of study limitations imposed by simulation hardware technology limits projected for the recommended performance period. Simulation technology development required has been documented in the recommendations above, and in supporting Technical Needs addressed to AFHRL.

SCHEDULE SUMMARY ---- RECOMMENDED STUDIES



HIGH PRIORITY

Workload Metric Development
Workload Assessment under
  Degraded/Enhanced Modes
Situational Awareness & Target
  Acquisition with FLIR
Terrain Following/Terrain Avoidance
Radar Altimeter Integration
Intertial Navigation System
  Integration
Operational Training System
  Development
FLIR Image Generation Technology
Full Scale Tactial Simulation
  Development

MEDIUM PRIORITY

Heads Up/Down Display Alternatives
Interaction of Displayed Target
  Position with Field of View
Multi-Function Controls and Displays
Color Display Integration
Voice Warning System Integration
FLIR Simulation Data Base
  Development
Helmet Mounted Sights & Displays

LOW PRIORITY

Visual Accommodation-Cockpit vs HUD
Correlated Sensor/Image Processing
Electronic Synthesized Displays
Voice Control System Integration

SUMMARY OF RECOMMENDED STUDIES

	Supporting Documentation	Simulation Facility	Facility Upgrade	Sim Development Supporting Docs.
HIGH PRIORITY				
Workload Metric Development	AMD R&T Plan	CSDF	Recording Eq.	N/A
Workload Assessment Under Degraded/ Enhanced Modes	NAWSG Charter	CSDF/Full Scale Sim.	Extensive Dev. Required	2 ASD TNs
Situational Awareness	AFHRL TR	ASPR	Low Alt FLIR Simulation	ASD TN
Terrain Following/Terrain Avoidance	Survey Results	LAMARS MACs, CSDF, SAINT	Low Alt FLIR Simulation	ASD TN
Radar Altimeter Integration	"Quick Look"	LAMARS, CSDF	N/A	N/A
Inertial Navigation System Integration	ASD TN	AVSAIL, GTB	N/A	N/A
Operational Training System Development	"Quick Look"	N/A	N/A	N/A
FLIR Image Generation Technology	2 ASD TNs	N/A	N/A	N/A
Full Scale Tactical Simulation Development	2 ASD TNs	To be developed	N/A	2 ASD TNs

SUMMARY OF RECOMMENDED STUDIES (CONTINUED)

	Supporting Documentation	Simulation Facility	Facility Upgrade	Sim Development Supporting Docs.
MEDIUM PRIORITY				
Heads Up/Down Display Alternatives	ASD TN	LAMARS TACDEP, SAINT	Color CRTs	N/A
Interaction of Displayed Target Position with Field of View	2 ASD TNs	CSDF, ASPT	Lo Alt FLIR Simulation	2 ASD TNs
Multi-Function Controls & Displays	ASD TN	DIGISYN, LAMARS GD, MACS	Extensive Dev. Reqd.	None
Color Display Integration	ASD TN	To be developed	N/A	N/A
Voice Warning System Integation	ASD TN	DIGISYN, CSDF	Voice Warning	N/A
FLIR Simulation Data Base Development	TN Reqd	N/A	N/A	TN Reqd
Helmet-Mounted Sights & Displays	2 PMDs, ASD MOA	TACDEP, LAMARS	Lo ALt FLIR Simulation	LAMARS MOA

SUMMARY OF RECOMMENDED STUDIES (CONTINUED)

	Supporting Documentation	Simulation Facility	Facility Upgrade	Sim Development Supporting Docs.
LOW PRIORITY				
Visual Accommodation-Cockpit vs HUD	AFAMRL TR	To be developed	N/A	N/A
Correlated Sensor/Image Processing	ASD TN	AVSAIL, LAMARS VIPER	Lo ALt FLIR Simulation	ASD TN
Electronic Synthesized Displays	3 ASD TNs	DIGISYN	Terrain Map Disp. Sys.	ASD TN
Voice Control System Integration	2 ASD TNs	LAMARS	N/A	None

SECTION V

STUDY DESCRIPTIONS

The order of the following recommended study write-ups reflects the general priorities as shown in the Schedule Summary (pg 6).

1. WORKLOAD METRIC DEVELOPMENT/APPLICATION

a. Problem Description/Data Base Deficiency: The issue of pilot workload becoming the limiting factor on mission success has gained much notoriety. The charter of the Night Attack Workload Steering Group (NAWSG) is to study the tactical night attack mission, considering the kinds of equipment under current development (LANTIRN) with particular emphasis on pilot workload questions. The three objectives of the NAWSG are to study pilot's workload capability, optimize pilot capability to perform and determine how to minimize pilot workload. These objectives must involve the development of valid, mission specific workload metrics. Subjective measurements and interviews are currently the most widely used pilot workload assessment techniques and are expected to remain so in the short-term. Other more objective measures have been demonstrated in the laboratory and in simulation. However, none are at a stage of development to rely upon for system design. Long term development of objective techniques are required and are ongoing. Some will be available in the time frame for evaluation of equipment currently under development.

b. Impact (LANTIRN or Long Term General): Current night attack system developments are dependent on a workload data base developed with totally subjective measurement techniques. Proposed objective assessment techniques will validate and refine the technical data base required.

c. Current/Ongoing/Related Efforts: For LANTIRN, the conjoint analysis technique of measuring pilot workload will be developed and used in conjunction with the CSDF real-time simulation studies. Consideration is being given to employing conjoint analysis with psychophysiological measures in LANTIRN flight tests. A method of cardiac variability analysis being employed with the Advanced Fighter Technology Integration and Integrated Flight Fire Control programs is under consideration for use with LANTIRN. More sophisticated objective techniques will impact longer term night attack assessments. AFAMRL/HEG and USAFSAM/VNE have programs to assess operator performance and the effects of some operational stressor impacts on that performance. These include mission analysis techniques and subjective, behavioral, neuropsychological, psychophysiological, and biochemical metrics. In addition, the SAINT model (currently being used by AFAMRL) is an example of a mission/task model which allows gross preliminary assessment of workload within a mission scenario.

d. Supporting Documentation: AMD Research and Technology Plans, 7185/14 and 7930/10, Sept 80.

e. Recommended Study Description:

(1) Scope: Additional study is required to refine the subjective interview and rating scale techniques, including more work in the area of conjoint analysis. If cardiac variability analysis is to be employed in the flight tests of LANTIRN, the same type of data must be obtained on the pilot population participating in the planned CSDF simulation studies. New objective measures must be developed, validated in the laboratory and in simulation, and applied. The research program should include improving mission task description and analysis methodology, and standardizing techniques for subjective, behavioral, neuropsychological, psychophysiological, and biochemical measurement. The investigation of various unobstrusive secondary tasks as loading tasks as well as direct measures of primary task workload needs to be continued. A neurophysiological test battery must be standardized for use in field testing as soon as practicable. Candidate measurements may include the cortical evoked response and other neurophysiological recordings.

(2) Organization to Conduct: AFAMRL/HEG, USAFSAM/VNE

(3) Facility to Use: AFAMRL's Workload and Ergonomics Branch Performance Assessment Facility; CSDF; AFFTC Flight Test Facility.

(4) Facility Upgrade Required: Neurophysiological recording equipment on CSDF and inflight recording capabilities.

(5) Study Limitations: Critical mass of data required for test battery development.

f. Recommended Simulation Technology Development and Supporting Documentation: N/A.

2. WORKLOAD ASSESSMENT UNDER DEGRADED AND ENHANCED MODES - LANTIRN

a. Problem Description/Data Base Deficiency: LANTIRN systems have been described as enhancing the pilot's capability to perform his mission successfully while reducing his workload. It is highly desirable to assess the amount of workload experienced with a full-up LANTIRN system. Of equal importance is the assessment of the pilot's workload when any one or several of the enhancements afforded by LANTIRN fails. The identification of chokepoints during the mission can be useful feedback to system design/operation.

b. Impact (LANTIRN or Long Term General): The enhancements referred to herein are LANTIRN specific. The degradations to be discussed are related to the LANTIRN components. This assessment is also important for the long term night attack problem as new advances are made in technology to accomplish the mission.

c. Current/Ongoing/Related Efforts: AFAMRL/HEG (Workload and Ergonomics Branch) is studying various ways to measure pilot workload under specific mission scenarios (see previous writeup). The SAINT computer model currently being applied for LANTIRN allows evaluation of workload under different operational assumptions for identification of chokepoints in the mission timeline.

d. Supporting Documentation: NAWSG Charter.

e. Recommended Study Description:

(1) Scope: As a part of the real-time simulation program to be conducted at the CSDF, it is recommended that the effect of various degraded modes of LANTIRN operation on pilot workload be evaluated. Workload measures under a full functioning system should serve as the baseline.

(2) Conditions of degradation should also be run through the SAINT model for cross-validation of mission chokepoints found in the real-time simulation. Similarly, operator actions resulting from various levels of equipment performance as simulated in the CSDF should be incorporated within SAINT as appropriate. Further, validation should be conducted in LANTIRN DT&E and OT&E flight tests where possible. Examples of system failures to be introduced during the mission should include variations in INS drift rates, failure of TF/TA, radar altimeters, auto recognizer, snap look capability, and degradation of FLIR video due to atmospheric conditions.

(3) Organization to Conduct: AFAMRL/HEG, ASD/ENECH

(4) Facility to Use: SAINT Model, CSDF, AFFTC Flight Test. A full-scale tactical simulation facility is required to suppport long term efforts.

(5) Facility Upgrades: A generic test bed aircraft would add an additional capability which we currently do not have. This generic test bed should allow the flexibility to introduce workload metrics to evalute pilot performance under varying mission requirements, new avionics systems, degraded modes of avionics and differing cockpit configurations. An integrated low altitude FLIR simulation capability is required.

(6) Study Limitations: Required iterative process not expected to address all possible failure mode combinations.

f. Recommended Simulation Technology Development and Supporting Documentation: TN-ASD-AFHRL-1705-77-64 (Ground Mapping Sensor Simulation).

3. SITUATION AWARENESS AND TARGET ACQUISITION WITH FLIR IMAGERY

a. Problem Description/Data Base Deficiency: The use of FLIR imagery in other than benign weather environments can be expected to tap interpretative skills of the pilot which he may not be prepared for. The FLIR image represents a part of the thermal spectrum in which the pilot has no experience. The visible spectrum relates to reflected light energy, while the sensed IR spectrum results primarily from emitted radiation. Moreover, the apparent signature of a target and its background in the IR domain undergoes considerable change throughout a diurnal (daily) cycle, such that inversions in target vs background emissions occur sometime after sunset as well as after sunrise. Due to the inherent differences between FLIR returns and other possible sensor data (i.e., TV, LLLTV, radar) as well as a possible map display, a need exists to develop pilot expertise necessary to assure adequate familiarity with FLIR imagery across the range of realistic weather and diurnal conditions. At a minimum, a training program should be established which addresses expected sensor modality differences and provides hands-on experience in tuning brightness and contrast controls for optimum information extraction.

b. Impact (LANTIRN or Long Term General): This is a generic problem that should be addressed for both LANTIRN and long-term night attack systems.

c. Current/Ongoing/Related Efforts: (1) Work Unit 2313T205 (Psychological Aspects for Sensor Simulation - AFHRL/LRLG); (2) Automatic Gain Control to be incorporated in Electro-Optical Viewing System on B-52.

d. Supporting Documentation: Vision Requirements for B-52 Sensor Simulation, AFHRL-TR-81-8, Vols I & II (C).

e. Recommended Study Description:

(1) Scope: Since previous research indicates that observers typically adjust video displays in suboptimal ways (usually resulting in high contrast and attendant black level clipping) the feasibility of automating brightness and contrast control settings based on average sensed reflectivity or emissivity (depending on the sensor) as well as ambient display/cockpit illumination should also be investigated. It is suggested that AFHRL take the lead in developing appropriate training materials and curriculum in cross-sensor interpretation and that AFWAL evaluate technology for automatic brightness and contrast control.

(2) Organization to Conduct: AFHRL/OT and AFWAL/AA.

(3) Facility to Use: ASPT (for on-line studies) augmented with laboratory training materials.

(4) Facility Upgrades Required: A high resolution FLIR simulation capability is required to emulate FLIR returns under low level flight.

(5) Study Limitations: Available library of FLIR sensor photos will limit training exposure.

f. Recommended Simulation Technology Development and Supporting Documentation: FLIR simulation technology and TN-ASD-AFHRL-1705-77-64 (Ground Mapping Sensor Simulation).

4. TERRAIN FOLLOWING/TERRAIN AVOIDANCE - MANUAL VS AUTOMATIC

a. Problem Description/Data Base Deficiency: In order to minimize one's vulnerability to threats in the night, all-weather attack scenario, it is imperative to maintain low altitude flight. This low altitude requirement dictates the need for a terrain following (TF) system. The question of whether this implementation should be automatic or manual drives the priority of this issue to near the top. The combined efforts of the Quick Look Team flight tests, ASD/ENE and Systems Research Laboratory (SRL) surveys indicate that "realistic single seat night operations below 500 feet AGL require automatic TF."

b. Impact (LANTIRN or Long Term General): Since LANTIRN (for at least the A-10) will only incorporate a manual TF/TA system, the answer to the amount of automation becomes a long-term night attack issue.

c. Current/Ongoing/Related Efforts: AFWAL/FIGL is the OPR for investigating advanced automatic TF/TA concepts. They have an on-going contract with McDonnell Douglas to develop algorithms for simultaneous TF/TA at low altitude with high G maneuvering. As a part of this contract, the feasibility of carrying an on-board section of digital landmass data base to accommodate the auto TA problem is being addressed. In addition, AFWAL/FIGL and FIGD have begun two in-house programs in the area of TF/TA algorithm development and the incorporation of threat data (Purple Haze) into the TF/TA work. The Cartographics Applications for the Tactical and Strategic Operations program being pursued at Rome Air Development Center will look into the feasibility of digital landmass data for fighter and strategic applications.

d. Supporting Documentation: No Technical Need exists. However, the A-10, F-16, F-15, and F-4 D&E pilots interviewed in the SRL survey and the fighter pilots responding to the ASD/ENE questionnaires consistently stressed the desire and need for automatic TF/TA systems for the night, all-weather mission.

e. Recommended Study Description:

(1) Scope: Specific recommendations for mid-term and long-term research into TF/TA include: (1) control law requirements for auto TA; (2) ride quality questions; (3) system reliability; (4) ease of operation; (5) interaction of FLIR sensor/display performance and FOV with ability to monitor auto or manual TF/TA system performance; (6) integration of the sensor (terrain) data with flight path data; (7) pilot override provisions and resulting workload; (8) concept of auto TF with a manual TA display: (9) efforts of higher airspeeds on pilot interaction with TF/TA displays; (10) resolution required for an on-board digital data base. The human factors aspects associated with either a manual or auto TF/TA system are implied in some of the above studies (e.g. (6)). Pilot workload measurements will serve as the basis for evaluation in these efforts.

(2) Organization to Conduct: AFWAL/FIGD, ASD/ENECH and AFAMRL/HEA.

(3) Facilities to Use: AFWAL/FIGD (Flight Dynamics Lab Engineering Simulation Facility), McDonnell Douglas, CSDF. SAINT model could be implemented for (8), (9) or (10).

(4) Facility Upgrades Required: Algorithms implementation for auto TA, FLIR video display on HUD, FLIR video on HDD, DMA digital data base.

(5) Study Limitations: Fidelity of simulated FLIR imagery will impact generalizability of data.

f. Recommended Simulation Technology and Supporting Documentation: FLIR simulation technology TN-ASD-AFHRL-1705-77-64 (Ground Mapping Sensor Simulation).

5. RADAR ALTIMETER

a. Problem Description/Data Base Deficiency: The list of essential equipment for night low level missions summarized from the ASD/ENE and SRL pilot surveys both included the need for a radar altimeter. A radar altimeter as currently defined will only allow the pilot to know his height above the ground directly below him. The problem is that at higher air speeds, the information being processed by the radar altimeter and fed back into the cockpit is after the fact. This could cause the pilot to either fly into the ground or demand a reaction on his part that might be impossible or very task loading at a minimum. There is a need for the identification of an optimal range for the radar altimeter based upon pilot reaction time data.

b. Impact (LANTIRN or Long Term General): LANTIRN will include a radar altimeter, however, the question of the best operating range becomes a longer-term night attack issue.

c. Current/Ongoing/Related Efforts: None.

d. Supporting Documentation: "Quick Look" results.

e. Recommended Study Description:

(1) Scope: Methods to obtain altitude data such as a laser ranging capability or weather radar should be examined. The human factors issue of what is the pilot's optimal reaction time to knowledge of terrain altitude ahead of his aircraft will drive the range at which the sensor processes forward looking altitude information. Studies should be conducted under various manipulations of terrain and air speed to determine radar altitude and range display requirements. Also of importance is the manner in which the pilot is alerted to terrain above his set clearance altitude. Studies should be performed to investigate the use of a HMD for this purpose. Voice warning, as well as the use of lights and tones or combinations of all three may be applicable (see voice warning writeup herein).

(2) Organization to Conduct: AFWAL/FIG, ASD/ENECH

(3) Facility to Use: AFWAL/FIGD, CSDF

(4) Facility Upgrades Required: Implementation of different pilot warning methods.

(5) Study Limitations: None.

f. Recommended Simulation Technology Development and Supporting Documentation: None.

6. INERTIAL NAVIGATION SYSTEM (INS)

a. Problem Description/Data Base Deficiency: The INS accuracy is a fundmental critical issue in all tactical missions. The pilot must update the INS very frequency if the desired accuracy is to be obtained. Solutions to this problem fall in two areas. The first is development of a more accurate INS, and the second is development of an improved INS update capability (preferably automatic). The pilot workload associated with INS operation is directly proportional to the update requirements. Manual updates are time consuming and difficult. The emphasis in future systems should be development of an automatic update capability (e.g., via GPS or stored digital terrain data).

b. Impact (LANTIRN or Long Term General): The INS accuracy and update requirements are very critical to LANTIRN and improvement in this area would have a direct result on that and all follow-on systems. Thus, this requirement has both short and long-term general impact.

c. Current/Ongoing/Related Efforts: Multi-function flight control reference system (AFWAL/FIGL), Low Altitude Navigation Augmentation System (AFWAL/AAA).

d. Supporting Documentation: TN-ASD-AFWAL/AA-1707-77-07 (Integrated Inertial Reference Assembly)

e. Recommended Study Description:

(1) Scope: Both INS accuracy and rapid/easy update should be pursued with emphasis on producing a cost effective system. The human factors aspects of alternative manual update schemes should be studied. In addition, the full spectrum of updating should be analyzed starting with manual methods, then semi-automatic (i.e., use of a helmet-mounted sight or display) and continuing to a fully automated INS update. The impact of these schemes on pilot workload should be evaluated.

(2) Organization to Conduct: AFWAL/AAA, AFWAL/FIGL

(3) Facility to Use: AVSAIL Facility, Generic Test Bed (GTB)

(4) Facility Upgrades Required: N/A

(5) Study Limitations: Final answers available through flight test evaluations only.

f. Recommended Simulation Technology Development and Supporting Documentation: None.

7. OPERATIONAL TRAINING SYSTEM DEVELOPMENT

a. Problem Description/Data Base Deficiency: The introduction of any new weapons system creates new and unique training requirements. Training programs for modern aircraft systems are often based on extensive use of flight simulators, weapons system trainers, and other sophisticated, complex and expensive ground training equipment. Historically, simulation training equipment has been acquired as an afterthought to the primary weapons system development. This approach has often resulted in deployment of operational hardware without benefit of critically needed training equipment. Unlike many other systems, LANTIRN simulation time cannot be replaced with aircraft flight hours. Use of FLIR imagery by the pilot to control the aircraft (at low altitude/high speed) for navigation, and for target identification/verification is expected to tap interpretive skills for which the pilot has no experience base. LANTIRN field deployment success is seen as highly dependent on the availability of a comprehensive training system to support the LANTIRN introduction.

b. Impact (LANTIRN or Long Term General): Although training development is a generic problem for all weapons systems, LANTIRN impact is expected to be particularly critical in the period prior to and during system introduction.

c. Current/Ongoing/Related Efforts: Budgetary cost estimates have been researched by ASD/YW for development of both LANTIRN part-task trainers and F-16/A-10 weapons systems trainer updates.

d. Supporting Documentation: Definitive training requirements have not been documented by either the weapon SPOs or the user. "Quick Look" results strongly support training systems development.

e. Recommended Study Description:

(1) Scope: Recommend the System Program Office for LANTIRN, the F-16 and A-10 pursue definition and develoment of an instructional system and associated ground training equipment for LANTIRN. Contract support of this effort may be required (in lieu of Tactical Air Command Support).

(2) Organization to Conduct: LANTIRN SPO, F-16 SPO, A-10 SPO or TAC.

(3) Facility to Use: N/A

(4) Facility Upgrades Required: N/A

(5) Study Limitations: N/A

f. Recommended Simulation Technology Develpment and Supporting Documentation: N/A

8. FLIR IMAGE GENERATION TECHNOLOGY

a. Problem Description/Data Base Deficiency: Flight simulations supporting night attack technology development and night attack systems training require a FLIR sensor image generation capability. The image generation must: (1) be correlated and integrated to the other simulated flight systems (EW, Radar, Flight, etc); (2) include a gaming area (data base) capable of supporting unconstrained flight over wide areas at low altitude and high airspeeds; and (3) provide image fidelity equivalent to that produced by sensors functioning in the real world as affected by weather and atmospheric effects. Such a system capability is not within the state of the art. No FLIR terrain imagery data base presently exits.

b. Impact (LANTIRN or Long Term General): A FLIR sensor simulation capability is critical to development of simulation required in support of both near and long term night attack training and weapons systems development requirements.

c. Current/Ongoing/Related Efforts: Full Scale Tactical Simulation - see recommendations.

d. Supporting Documentation: TN-ASD-AFHRL-0508-77-65 (Flight Simulator Visual Systems and Electro-Optical Systems); TN-ASD-AFHRL-1705-77-64 (Ground Mapping Sensor Simulation)

e. Recommended Study Description:

(1) Scope: Laboratory studies are needed to define the level of FLIR simulator fidelity required. Recommend immediate initiation of a FLIR simulation technology development program.

(2) Organization to Conduct: AFHRL/OT

(3) Facility to Use: None required.

(4) Facility Upgrades Required: N/A

(5) Study Limitations: N/A

f. Recommended Simulation Technology Development and Supporting Documentation: A concept paper for establishment of FLIR simulation technology should be developed as soon as practicable.

9. FULL SCALE TACTICAL SIMULATION DEVELOPMENT

a. Problem Description/Data Base Deficiency: Future night attack training and current development programs will be dependent on use of a fully integrated weapons systems trainer; a ground based simulation device which accurately replicates the pilot's total in-flight environment including the cockpit, out-the-window scene, radar, EW/ECM, munitions, sensor displays, etc. Current state of the art does not support low risk development or integration of such a capability. Extensive development is required, particularly in the FLIR image generation area.

b. Impact (LANTIRN or Long Term General): The immediate need for such a device is expected to continue for several years in the future.

c. Current/Ongoing/Related Efforts: AFSC/XR has directed planning for development/integration of such a facility.

d. Supporting Documentation: HQ AFSC/XRL Message 021945Z Sep 80 and HQ USAF/RDQ Message 197015Z June 80; TN-ASD-AFHRL-0508-80-65 (Fidelity of Simulation and Transfer of Training); TN-ASD-AFHRL-0508-77-65-(2) (Flight Simulator Visual Systems and Electro-Optical Systems); TN-ASD-AFHRL-1705-77-64-(1) (Ground Mapping Sensor Simulation).

e. Recommended Study Description:

(1) Scope: Recommend the timely development and acquisition (by 1986) of a full scale tactical simulator facility required to support the aircraft development community to develop the simulation technology required to support operational training simulator development.

(2) Organization to Conduct: AFHRL/OT (Technology Development) and AFWAL/FIG (Facility Development).

(3) Facility to Use: New facility development is required.

(4) Facility Upgrades Required: See above.

(5) Study Limitations: N/A

f. Recommended Simulation Technology Development and Supporting Documentation: TN-ASD-AFHRL-0104-78-64-(1) (Visual System Requirements Verification and Trade-off Analysis for Aircrew Training Simulation); TN-ASD-AFAMRL-AFHRL-0602-80-66-(1) (Establishment of Sensory/Perceptual Data Base for Aircrew Training Devices).

10. HEAD UP/DOWN DISPLAY ALTERNATIVES

a. Problem Description/Data Base Deficiency: Results from the "Quick Look Team" as well as the ASD/ENE pilot survey indicate a strong desire to minimize head-down time during the mission. Since everything the pilot needs for successful completion of the mission cannot be displayed and understood on a HUD, research needs to be conducted on what information should be on the HUD and what can be placed on a HDD. The desired situation is one where the pilot only has to cross check the HDDs quickly and gets all the information he needs so he can then return to viewing out of the cockpit.

b. Impact (LANTIRN or Long Term General): The major impact on LANTIRN is determining the amount of information that can be displayed on the HUD and insuring the remaining information is available on a front panel HDD. HUD vs HDD integration of information will continue to be a long term problem.

c. Current/Ongoing/Related Efforts: Work is being done by the Flight Dynamics Laboratory and the Avionics Laboratory to determine methods of consolidating displays for combined, computer generated presentations. Work is also being performed in the area of improving HUD and HDD capabilities. The work AFAMRL/HEA is doing in helmet-mounted displays also shows much promise in this area. Related work areas are AFTI-F-16 simulations (AFWAL/FIGD), Advanced Fighter Cockpit Program (AFWAL/FIGR), Tactical Flight Management (AFWAL/FIGL), Pictorial Format Program (AFWAL/FIGR) and Helmet-Mounted Displays (AFAMRL/HEA).

d. Supporting Documentation: TN-ASD-AFWAL/AA-FI-AFAMRL-0508-80-72 (Aircraft Display Information and Placement Technology).

e. Recommended Study Description:

(1) Scope: More work needs to be performed in integrating the total amount of information so that the transition from HUD to HDD can be smooth and easy. Some recommended studies are: (1) Determining the number of CRTs necessary in the cockpit as well as the size of these CRTs. Present trends appear to be for the placement of two or three CRTs on the front cockpit panel. Research needs to continue to evaluate the best way to provide the pilot the necessary information with a minimum of required interpretation time; (2) the problem of consolidating the information displayed to the pilot on the HDDs seems to be implying two possible solutions. The first is the use of color CRT displays as an aid in information intepretation. The second is the use of pictorial formats or computer generated displays that combine many present-day displays into a small number of pictorial displays. Work in both these

areas is ongoing at AFWAL/FIGR and continued support of this work is critical; (3) The application of helmet-mounted displays (HMD) also shows considerable promise in this area. The key benefit of this type of display is a hemispherical field of regard; (4) Advances in Cockpit technologies have also opened the door to new solutions to these problems. The AFWAL Avionics Laboratory's Airborne Electronic Terrain Map System and AFWAL Flight Dynamics Laboratory's Terrain Masking/Threat Avoidance Displays (Purple Haze) have considerable application to these problems. Both of these programs rely on the Defense Mapping Agency's (DMA) digital land mass data to produce a synthetic display. The benefit of these systems is improved information display integration which will provide the pilot an increased night/all-weather capability.

(2) Organization to Conduct: AFWAL/FIG, AFAMRL/HEA, ASD/EN

(3) Facility to Use: The LAMARS Facility (AFWAL/FIGD) is undergoing modification to install an AFTI F-16 cockpit with two MFDs. There is an excellent opportunity to analyze the HUD/HDD issue for the F-16 in this facility. The SAINT model (AFAMRL/HEA) could also be used to investigate head-up vs head-down alternatives with particular emphasis on pilot workload effects. Similarly, long term solutions to some of the HUD vs HDD problems can be evaluted by AFAMRL/HEA in the TACDEP (Tactical Aircraft Cockpit Development and Evaluation Program) presently in develoment.

(4) Facility Upgrades Required: Addition of Color CRTs.

(5) Study Limitations: Generalization of study results will be constrained to the mission phases and vehicle dynamics peculiar to the simulation facilities used.

f. Recommended Simulation Technology Development and Supporting Documentation: None.

11. INTERACTION OF DISPLAYED TARGET POSITION WITH SENSOR FIELD-OF-VIEW AND FIELD-OF-REGARD

a. Problem Description/Data Base Deficiency: Quick Look flight test results indicate an inordinate increase in pilot workload if the target is not within the sensor/display field-of-view and that; (a) "a wide field-of-view sensor is required to compensate for navigation system inaccuracies and to provide for target area acquisition" and (b) "a high resolution sensor is required to define small tactical targets within the target area at sufficient range to allow delivery of current munitions." The Quick Look Team also "confirmed that effective use of the high resolution sensor (on the F-111F Pave Tack system) requires a slewing capability to place the target in the narrow field-of view"... and that "the multiple tasks required during target attack precludes the pilot dedication necessary for manual tracking." These results suggest the need for a comprehensive simulation and evaluation of the trade-offs among INS accuracy, sensor performance (in terms of modulation transfer across spatial frequencies), sensor field-of-view and sensor field-of-regard.

b. Impact (LANTIRN or Long Term General): This area represents a major limitation in night attack system performance prediction capability and data base development for engineering design trade-offs.

c. Current/Ongoing/Related Efforts: LANTIRN SPO supported CSDF and SAINT simulations.

d. Supporting Documentation: TN-ASD-AFWAL/AA-1707-77-07 (Integrated Inertial Reference Assembly); TN-ASD-AFAL-2005-79-04 (Next Generation Tactical Targeting System Technology).

e. Recommended Study Description:

(1) Scope: Due to the impact of the above cited variables on total workload, it is recommended that they be evaluated in as close to a full-mission simulation environment as possible (including auto target recognizer and auto vs manual TF and ECM capabilities). The Crew Station Design Facility is suggested as the most viable simulation capability to support this research, although generalizations from simulated FLIR performance will be limited. The results of this study will be used to guide the development of INS, FLIR sensor (performance and slew windows) and display systems.

(2) Organization to Conduct: ASD/ENECH; AFHRL/OT as backup.

(3) Facility to Use: CSDF; ASPT as backup.

(4) Facility Upgrades Required: Improved FLIR simulation fidelity.

(5) Study Limitations: FLIR simulation fidelity; extrapolation across broad range of other subsystem performance effects.

f. Recommended Simulation Technology Development and Supporting Documentation: TN-ASD-AFHRL-0104-78-64 (Visual System Requirements Verification and Trade-off Analysis for Aircrew Training Simulation); TN-ASD-AFHRL-0508-77-65 (Flight Simulator Visual Systems and Electro-Optical Systems).

12. MULTI-FUNCTION CONTROLS AND DISPLAYS (MFCD)

a. Problem Description/Data Base Deficiency: As demonstrated by the Navy F/A-18 and MSIP F-16 aircraft, the use of multi-function controls and displays is a partial solution to the crowded cockpit problem. (Proper integration provides the remainder of the solution.) The classic human engineering question of where to place single purpose controls and displays in the cockpit has been replaced by one of what is the information necessary to display on the MFCD so the pilot can perform a particular mission phase. The MFCDs now provide the flexibility to present many different types of information. The pilot has the capability to access a multitude of information simply by depressing a few keys. The goal of MFCD research should be one of determining the best way to provide the pilot what he needs, when he needs it and to minimize the amount of non-essential information.

b. Impact (LANTIRN) or Long Term General): The MSIP F-16 aircraft will contain multi-function displays and all are also scheduled to receive LANTIRN retrofits.

c. Current/Ongoing/Related Efforts): Basic research is being performed by AFWAL/FIGR and AFWAL/AAAT on the application of MFCDs in the cockpit. Work is also ongoing by these organizations to determine if the application of color CRTs will benefit this area. Existing work areas are: Advanced Fighter Cockpit Program (AFWAL/FIGR); Tactical Flight Management (AFWAL/FIGL); Advanced Systems Avionics (ASFWAL/AAA), and; Pictorial Format Program (AFWAL/FIGR).

d. Supporting Documentation: TN ASD-AFWAL/AA/FI/AFAMRL-0508-80-72, (Aircraft Display Information and Placement Technology).

e. Recommended Study Description:

(1) Scope: The key issues requiring study include the display of information in the clearest, most easily understood fashion while providing this information with minimum required head-down time. The use of color displays with pictorial formats (computer generated displays) shows considerable promise in this area.

(2) Organization to Conduct: AFWAL/FIGR, AFWAL/AAAT and AFAMRL/HEA.

(3) Facility to Use: Digital Synthesis Facility (AFWAL/FIGX), LAMARS (AFWAL/FIGD), General Dynamics (MSIP F-16), and McDonnell Douglas (F-18).

(4) Facility Upgrades Required: Color CRTs in the cockpit (see Color Displays writeup herein also).

(5) Study Limitations: Care must be taken when generalizing to cockpits other than those used in this research.

f. Recommend Simulation Technology Development and Supporting Documentation: MFCD research requires full scale simulation facility and workload assessment capability.

13. COLOR DISPLAY INTEGRATION:

a. Problem Description/Data Base Deficiency: It is obvious that color displays will play a major role in cockpit instrumentation of the future. Studies performed in the benign environments of the ASD Crew Station Design Facility (CSDF) and on the AFWAL/FIGR DAIS cockpit (now referred to as DIGISYN) demonstrated a significant reduction in pilot workload when a color display was used to portray JTIDS (Joint Tactical Information Distribution System) information, versus a monochrome display. Results from the CSDF study indicate that a properly adjusted color JTIDS display can make the difference as to whether or not a single crewmember can perform the tactical mission satisfactorily. Optimum integration of flight qualified color displays for both day and night applications place stringent demands on display performance (i.e., maintaining discriminably separate colors across a broad range of luminance levels) as well as the operator's ability to effectively use the color. Color displays presently anticipated for cockpit applications incorporate either a shadow mask or a beam penetration CRT with an appropriate filter (neutral density, notched, or directional) to make them more or less impervious to direct sun illumination. Since installation of color displays for night use only seems unlikely, development of techniques to assure utility of these displays across the spectrum of luminance levels required for stark nighttime to full sun illumination is required. Under these conditions, at least four classes of potentially debilitating visual phenomena are apparent. The first, chromostereopsis, refers to the fact that colors at the spectral extremes (blue and red) are not imaged on the retina at a consistent location for all people. The result is that some observers perceive blue objects to be behind, and red objects to be in front of the display surface. Another segment of the population experiences the opposite effect, while the remainder seems unaffected. The second effect creates an apparent movement or jumping of highly saturated (static) pure color objects in the plane of the display. This effect is likely due to involuntary saccadic eye movements that are normally a biologically adaptive response to minimize fatiguing of retinal receptors but in this case produces apparent movement due (supposedly) to the unusual chromatic purity produced by modern phosphors. The third effect is washout of colors under high illumination. The fourth effect is attributable to the interaction of refresh rate and phosphor persistence and results in apparent flicker of the symbology under high ambient illumination.

b. Impact (LANTIRN or Long Term General): This is a long term generic problem.

c. Current/Ongoing/Related Efforts: None

d. Supporting Documentation: TN-ASD-AMRL-AFWAL/FI-0508-81-03 (Human Factors and Testing Requirements for Airborne Color Displays).

e. Recommended Study Description:

(1) Scope: It is recommended that laboratory studies be performed using representative state of the art shadow mask and beam penetration displays to: (1) quantify the optical performance of these devices across the full range of ambient, lighting conditions from dark to full sun illumination; (2) quantify their effects on observer performance; and (3) develop solutions to the problems named above.

(2) Organization to Conduct: AFAMRL/HEA

(3) Facility to Use: None presently available. Investment of $200K for symbol generator and state of the art color displays required.

(4) Facility Upgrades Required: N/A

(5) Study Limitations: Applicable to only color display equipped cockpits.

f. Recommended Simulation Technology Development and Suppporting Doscumentation: N/A.

14. VOICE WARNING SYSTEM INTEGRATION

a. Problem Description/Data Base Deficiency: Comments by the Quick Look Study Team indicate a desire to have radar altitude information displayed "wherever the pilot is looking". A viable alternative to shotgun display of this data throughout the cockpit is voice warning. A properly implemented system would augment the existing system of light signals and should be selectable at the option of the pilot so that in a heavy or critical voice traffic environment, the pilot will not have a critical voice transmission interrupted by a voice warning or will not miss a voice warning because it appears to be just another voice on the airways. A tone or chime preceeding the voice warning may serve as an alerting signal that a voice warning will follow., Voice warning may also be effective for identifying critical subsystems failure such as the TF Radar.

b. Impact (LANTIRN or Long Term General): Since voice warning may substantially alleviate pilot workload at low clearance planes, this area is of relatively high priority having both near and long term impact.

c. Current/Ongoing/Related Efforts: None

d. Supporting Documentation: TN-ASD-AFAMRL-AFWAL-0508-80-68 (Warning, Caution, and Advisory Annunciator System Design and Evaluation Criteria).

e. Recommended Study Description:

(1) Scope: A study should be conducted to determine the potential benefit and optimum implementation of voice warning schemes, including what characteristics the voice should have, the message(s) to be conveyed and at what volume, and pilot acceptance of these systems. A comprehensive evaluation would compare alternative alerting schemes such as tactile (e.g., stick, seat or throttle shakers) or novel visual display presentations. It is recommended that the research be conducted by either AFWAL/FIGR in their tactical (DIGISYN) simulator or by ASD/ENECH in the Crew Station Design Facility using the present A-10 or future F-16 cockpits. AFAMRL/BBA should be consulted regarding criteria for preventing aural confusion and MIL-STD-411 provides additional guidance.

(2) Organization to Conduct: AFWAL/FIGR or ASD/ENECH

(3) Facility to Use: DIGISYN or CSDF

(4) Facility Upgrades Reqired: Voice warning and triggering algorithms

(5) Study Limitations: "Pucker factor" of real world low altitude flight not incorporated in simulator evaluations. Simulator results may therefore be highly conservative.

f. Recommended Simulation Technology Development and Supporting Documentation: None.

15. FLIR SIMULATION DATA BASE DEVELOPMENT

a. Problem Description/Data Base Deficiency: Ongoing and future simulation hardware development programs will include integration of a FLIR sensor image generation capability. However, no terrain data base exists in any form (digital, film, or model) which supports the wide area, long track, low level requirements levied by night attack training systems of the future. Developments of FLIR image generation systems, and development of fully integrated full scale simulation in turn, are dependent on the development of a FLIR terrain data base.

b. Impact (LANTIRN or Long Term General): Both short and long term impact on development of night attack weapons systems and training equipment.

c. Current/Ongoing/Related Efforts: AFWAL Project 2004 (FLIR Sensor Performance Characteristics)

d. Supporting Documentation: None; TN required.

e. Recommended Study Description:

(1) Scope: Recommend immediate initiation of development efforts required to produce an integrated, high resolution, low level, FLIR terrain data base.

(2) Organization to Conduct: Defense Mapping Agency

(3) Facility to Use: N/A

(4) Facility Upgrades Reqired: N/A

(5) Study Limitations: N/A

f. Recommended Simulation Technology Development and Supporting Documentation. None exist. Initiation of a TN stating specific requirements is appropriate.

16. HELMET-MOUNTED SIGHTS AND DISPLAYS

a. Problem Description/Data Base Deficiency: Questions of cockpit real estate and display size will continue to plague cockpit designers, as will techniques for sensor slewing and weapon aiming which minimize pilot workload. Helmet-mounted Sights and Displays (HMS/D) offer a unique and biologically natural means to solve these problems, since the apparent size of the display may be far larger than instrument panel space would allow and sensor field-of-regard or weapon aiming could be accomplished with simple head movement. Major strides have been made recently by AFAMRL in the development of unobtrusive and lightweight head attitude/position sensing equipment, and except for physical and electrical interface considerations, its use in operational aircraft is not application sensitive. However, the technologies and design tradeoffs that must be made for the application of HMDs to the operational environment are quite complex and extremely application sensitive. Due to these special factors, the planned use of HMDs in operational applications has been limited. However, important recent advancements have been made in HMD related technology areas, especially the CRT, and consideration for its use is now a realistic proposition on an application specific basis. See Appendix E.

b. Impact (LANTIRN or Long Term General): This is a long term requirement that may impact a second generation LANTIRN type system.

c. Current/Ongoing/Related Efforts: Tri-Service efforts to develop alternatives to CRTs for HMD applications (with emphasis on liquid crystal displays) are ongoing but need added emphasis. The Air Force OPR for solid state display technology development is AFWAL/AAAT. In a similar vein, AFAMRL/HEA is developing a ground based simulation facility within TACDEP (Tactical Aircraft Cockpit Development and Evaluation Program) which will exploit binocular HMD technology to provide a hemispheric HUD at far lower cost than present computer graphic visual (out-the-cockpit) scene simulators.

d. Supporting Documentation: PMD R-2033(5) 64708F/5973 (Visual Coupling Aids); PMD R-R2021(6) 64212F/2713 (Aircraft Instruments/Display Development); MOA, AFAMRL/HEA-ASD/AER (Visual Coupling Aids) Apr 79.

e. Recommended Study Description:

(1) Scope: Completely define operational requirements. Define HMS/D design and model performance on a suitable ground-based simulation facility. Based upon results, fabricate a prototype HMS/D and perform flight test and evaluation prior to operational go-ahead on a complete system. Estimated time to complete is 36 months.

(2) Organization to Conduct: AFWAL/A AT; AFAMRL/HEA; AFWAL/FIGD.

(3) Facility to Use: TACDEP, LAMARS

(4) Facility Upgrades Required: FLIR simulation capability

f. Recommended Simulation Technology Development and Supporting Documentation: MOA, AFAMRL/HEA-AFWAL/FIGD (Helmet-Mounted Visual Display for LAMARS), Feb 81.

17. VISUAL ACCOMMODATION FOR COCKPIT VS HUD INFORMATION

a. Problem Description/Data Base Deficiency: Visual accommodation (the ability of the eyes to change focal length) can be expected to have a subtle but potentially dramatic effect on the pilot's ability to perceive target and surround information on a HUD vs panel mounted display in a stark nighttime environment. Conventional HUD optics place the image (both sensor data and symbology) at optical infinity, while the cockpit environment (including the windscreen, support structure for the HUD combiner, as well as the combiner itself) tends to act as an accommodative trap to drive visual focusing closer than optical infinity. An analgous effect is obtained with telescopes and microscopes and is referred to as "instrument myopia". It is also known that in a dark environment, the resting state of accommodation is at approximately 0.8 meters (so-called "empty field myopia" or "dark focus"). Past research with helmet-mounted displays using narrow band green phosphors has also demonstrated that observers report "eye strain" as the display appears to go in and out of focus. The result of these effects is that the focusing of the HUD to optical infinity may not provide an optimal image to the pilot at night (or under the conditions where the outside world is not directly visible). Similarly, pilots consistently report perception of HUD displayed information to be poorer than when using a panel mounted CRT.

b. Impact (LANTIRN or Long Term General): This is a generic HUD problem that is especially complicated by a night attack scenario.

c. Current/Ongoing/Related Efforts: Recent report (AFAMRL-TR-80-116; Operational Problems Associated with Head-Up Displays During Instrument FLight) identifies "tendency of pilots towards disorientation while flying by reference to the HUD,... especially while flying in and out of clouds".

d. Supporting Documentation: See above.

e. Recommended Study Description:

(1) Scope: A comprehensive laboratory study is recommended in which realistic HUD vs head-down display (HDD) transitions are made under various HUD focal distances, display luminance (both HUD and HDD), ambient luminance and simulated phosphor spectral emissivity (using filters). An eye position and accommodation measurement capability would be required.

(2) Organization to Conduct: AFAMRL/HEA

(3) Facility to Use: A HUD simulation facility supporting this research does not now exist and would have to be specially developed. It is anticipated that AFAMRL could perform the research, assuming adequate support costs (estimated at $400K) were provided.

(4) Facility Upgrades Required: See above.

(5) Study Limitations: Ability to develop operational HUDs having adjustable focusing if found to be required.

f. Recommended Simulation Technology Development and Supporting Documentation: None.

18. CORRELATED SENSOR/IMAGE PROCESSING

a. Problem Description/Data Base Deficiency: The increased capability of on-board sensors and the continued need for night/all weather operations will mean the pilot will be relying more heavily on sensor information to perform the mission. However, single sensor systems will always have some limitations. For example, FLIR is severely degraded during adverse weather operation while radar is virtually unaffected. On the other hand, radar is very susceptible to ECM while FLIR is not. The key to solving this sensor problem is development of image processing algorithms and associated synthetic composite display formats that are most easily interpretable by the pilot. Data would be sampled by the sensor suite, screened as to potential information content, correlated across the sensor data sets, and displayed to the pilot in symbolic form. Integration of this capability will be critical since the pilot may still want to reference the raw information and cross check it with the composite display.

b. Impact (LANTIRN or Long Term General): This capability could be included in a second generation LANTIRN system and should improve future aircraft capabilities dramatically.

c. Current/Ongoing/Related Efforts: Display for Correlated Sensor Data (AFWAL/FIGR), Integrated Strike Avionics System (AFWAL/AAA).

d. Supporting Documentation: TN-ASD-AFHRL-1705-77-64 (Ground Mapping Sensor Simulation).

e. Recommended Study Description:

(1) Scope: Research and development in this area should be centered around improved sensor capabilities, processing algorithms, and composite (corrrelated) sensor display formats. The human factors aspects of integrating this capability in the cockpit needs special attention. Evaluations should treat both full-up as well as degraded modes of operation. Manual as well as automatic operation should also be evaluated. Initial proposed capabilities can be evaluated in a computer model such as SAINT (AFAMRL/HEA) to assess workload implications of this technology as early as possible. AFAMRL/HEA's VIPER (Visual Image Processing, Enhancement and Reconstruction) facility may be able to assist in implementation and evaluation of specialized image enhancement algorithms for optimum information extraction by the pilot.

(2) Organization to Conduct: AFWAL/AAA, AFWAL/FIGR/FIGD, AFAMRL/HEA

(3) Facility to Use: AVSAIL Facility (AFWAL/AAA), LAMARS (AFWAL/FIGD), VIPER (AFAMRL/HEA)

(4) Facility Upgrades Required: Extensive sensor simulation expansions.

(5) Study Limitations: Simulation in this area is severely limited due to the quality of FLIR, RADAR and LLLTV simulations available.

f. Recommended Simulation Technology Development and Supporting Documentation: TN-ASD-AFHRL-1705-77-64 (Ground Mapping Sensor Simulation).

19. ELECTRONIC SYNTHESIZED DISPLAYS

a. Problem Description/Data Base Deficiency: An ideal tactical night attack system would be totally unconstrained by weather and other atmospheric limitations to present sensor or out-the-cockpit visual capabilites. Ultimately, a completely autonomous capability is desirable which would rely on an on-board stored digital data base to provide the pilot with a synthetic view of the outside world around him (on a HUD, HDD or HMD). The heart of such a capability is the Airborne Electronic Terrain Map System (AETMS) under development by AFWAL/AAAT. Several technological issues are yet unresolved and must be evaluated/developed prior to implementation of this capability. These include hardware, software and human factors implications, and encompass data storage and retrieval, display update rate, data and display resolution, and perceptual interpretation issues.

b. Impact (LANTIRN or Long Term General): This is a long term solution to present sensor and ECM limitations. These systems are high risk/high payoff and require considerable laboratory research and development.

c. Current/Ongoing/Related Efforts: Airborne Electronic Terrain Map (AFWAL/AAA); Synthetic Terrain Program (AFWAL/FIGR); Pictorial Format Program (AFWAL/FIGR); Integrated Perceptual Information for Designers (AFAMRL/HEA).

d. Supporting Documentation: TN-ASD-AFWAL/AA/FI-AFAMRL-0508-80-72 (Aircraft Display Information and Placement Technology); TN-ASD-AFHRL-1705-77-64 (Ground and Mapping Sensor Simulation); TN-ASD-AFHRL/AFAMRL-0602-80-66 (Establishment of a Sensory/Perceptual Data Base).

e. Recommended Study Description:

(1) Scope: Research in this area should concentrate on the perceptual impact of alternative terrain portrayal schemes as dictated by present and proposed data storage, retrieval and display capabilities. Since current AETMS simulation is limited to non-real time display update rates, technology advancements are needed to provide a real-time pilot-in-the-loop evaluation capability. The application of color to enhance the utility of an AETMS is obvious and should be developed in conjunction with efforts cited in the "Color Display" writeup herein.

(2) Organization to Conduct: AFWAL/AAAT, AFWAL/FIGR, AFAMRL/HEA

(3) Facility to Use: Digital Synthesis (AFWAL/FIGX)

(4) Facility Upgrades Required: Improved Computer capability required to simulate terrain portrayal algorithms in both non-real and real-time.

(5) Study Limitations: Non-real time simulations will be limited to primarily subjective evaluations of the utility of an AETMS capability.

f. Recommended Simulation Technology Development and Supporting Documentation: TN-ASD-AFHRL-1706-77-64 (Ground Mapping Sensor Simulation).

20. VOICE CONTROL SYSTEM INTEGRATION

a. Problem Description/Data Base Deficiency: Night/adverse weather low-altitude ground attack operations often impose unacceptable manual and/or visual workload on aircrews. These loads are especially acute in single seat aircraft. The use of speech recognition devices for selected aircraft subsystem controls can decrease both types of workload and, conseqently, improve mission effectiveness. To date, no speech recognizers have been flown in high-performance aircraft. The range of environmental factors present in aircraft cockpits (g-force, vibrations, oxygen mask breath noise, etc) will have detrimental effects on recognizer performance. The degradation imposed by these environmental effects should be evaluated and solutions devised for a number of alternative speech recognizer designs to ensure development of a usable system at the earliest date. Additional work should be directed at identifying high payoff applications for speech input and validating these findings in flight test.

b. Impact (LANTIRN or Long Term General): This technology offers payoffs for both LANTIRN and generic, long term develoments.

c. Current/Ongoing/Related Efforts: AFTI/F-16 TCP 20-007, Voice Command System - AFWAL/FII/FIGR. Design Criteria for Speech Input/Output AFWAL/FIGR. Advanced Speech Technology in the Air-to-Ground Cockpit AFWAL/FIGR.

d. Supporting Documentation: TN-ASD-AFWAL/FI-AFAMRL/BB-AFATL-0508-81-64 (Voice Actuated Systems); TN-AD-AFATL/AMRL-2306/2307-80-2 (Voice Controlled Stores Management).

e. Recommended Study Description:

(1) Scope: The AFTI/F-16 Voice Command System TCP should be expanded to include other developers of flyable speech recogition hardware. These developers should be selected on the basis of significant advancements in their recognition strategy, rather than on simple enhancements to the Lear-Siegler device currently being developed for AFTI/F-16 Phase I flight test. At east three other companies are currently developing systems believed to be capable of being transitioned to military aircraft. In addition to concept validations, efforts should be made to: evaluate payoffs for the use of speech input in the air-to-ground role; determine the optimum system feed-back method(s), develop syntactical processors; identify training requirements imposed by speech input systems and evaluate the utility of voice interactive systems (speech in, speech out).

(2) Organization to Conduct: AFWAL/FII/FIGR

(3) Facility to Use: LAMARS

(4) Facility Upgrades Required: None.

(5) Study Limitations: Participation in a piggy-back manner on the AFTI/F-16 flight test must be of a non-interference nature with the primary goals of the AFTI program.

f. Recommended Simulation Technology Development and Supporting Documentation: None.

APPENDIX A

SURVEY OF GOVERNMENT AND INDUSTRY SIMULATION CAPABILITIES

The attached survey summarizes simulation facilities showing greatest promise for supporting short-term LANTIRN simulation studies. The survey includes facilities operated by the Air Force Human Resources Laboratory (Advanced Simulator for pilot Training - ASPT), the Air Force Aeronautical Systems Division (Crew Station Design Facility - CSDF), Martin Marietta Corporation (Simulation and Test Laboratory), the Air Force Wright Aeronautical Laboratories (Flight Dynamics Laboratory - LAMARS), McDonnell Douglas Corporation (Manned Air Combat Simulator - MACS), and the Rockwell Corporation (Columbus, Ohio Division). Attributes surveyed for each facility are shown in the right-hand column of each matrix. Numerous other facilities were reviewed; however, none provided capabilities which approach a full mission man-in-the-loop LANTIRN simulation capability required in the near term.

		Advanced Simulator for Pilot Training ASPT Williams AFB AZ Per: W. Richeson Nov 81	Crew Station Design Facility CSDF Wright-Patterson AFB OH Per: R. Geiselhart Nov 81	Martin Marietta Orlando FL Per: R. Bond Nov 81	Air Force Wright Aeronautical Labs Flight Dynamics Lab FDL - LAMARS Wright-Patterson AFB OH Per: D. Gumm Nov 81	McDonnell Douglas Corporation St. Louis MO Per: Larry Ross Roger Matthews Nov 81	North American Rockwell Columbus OH Per: J. Ætaliano Nov 81	
CREW STATION	COCKPITS AVAILABLE	A-10 and F-16	A-10 now/F-16 June 1982	A-10	Generic cockpit configured to A-10	F-15, F-18, AV8B & Generic Cockpits	2 Generic Cockpits	
	NUMBER OF PILOT SEATS	Single Seat	Single Seat	Single Seat	Single Seat	F-15 and F-18 have 2 seats	1 Cockpit has side by side	
	AVIONICS RECONFIGURATION TIME	2 hrs - 1 month	2 days	1 day	1 week	Hours w/Pre Design	9	11
	Aircraft Systems Controls and Instruments Panels: FLIGHT SYSTEMS	All	All	All	All	All for F-15 & F-18 plus generic CRT panels available	2 Seat Cockpit None	Single Seat Yes
	Aircraft Systems Controls and Instruments Panels: WEAPONS SYSTEMS	All	All	All	None			No
	Aircraft Systems Controls and Instruments Panels: COMMUNICATIONS	All	All	All	All			No
	CONTROL LOADING	McFadden - Both	McFadden	McFadden	McFadden	McFadden or aircraft duplicate		No
	PLATFORM MOTION	6 POST - 6 DOF	3 DOF	6 POST - 6 DOF	Boom - 5 DOF	Boom - 5 DOF		Yes
	G-SUIT	Yes	A-10 No F-16 Yes	None	Yes	Yes		No
	G-SEAT	Yes	A-10 No F-16 Yes	None	Planned - FY84	Yes		No
HUD	HEADS UP DISPLAYS NOW AVAILABLE	Standard F-16 F-15 HUD Used on A-10	F-16 MCIP HUD	Kaiser HUD - 200° FOV	Kaiser HUD - Spring 82	HUDs available - All cockpits	No HUDS available	
	APPROACH TO LANTIRN HUD SIMULATION	Would use WAC window mirror beamsplitter	WAC window mirror beamsplitter	None available could provide mirror beamsplitter	None - could project on dome.	Develop new optics Hughes holographic HUD 28°		
	SYMBOL GRAPHICS CAPABILITY	Yes-Full-No cost	Yes - Full	Yes - Full	Yes	Yes		
NAVIGATION SYSTEMS	INS SYSTEM SIMULATION	F-16 only. A-10 in 1 month	Yes	Partial	None presently could provide on six months' notice.	Yes	NONE AVAILABLE	
	INTEGRATED AIRCRAFT SENSOR CUEING (ARN-101)	Could provide on one month's notice	Yes	No		Yes - similar to ARN-101		
	INS CONTROL SYMBOLOGY ON HUD		Yes	No could provide		None - could provide		
	SIMULATED GPS (NAVIGATION SATELLITE) UPDATE		Could provide - 1 week's notice					
	MOVING MAP DISPLAY	Could provide on 6 months' notice	Will have digital map - Feb 83	Will have in 1982	None	Two types available film and digital		
	CORRELATION TO VISUAL, RADAR, FLIR, WEAPONS, MOVING MAP	None awaiting funding	V, TFR, F, W	V, F, W	V(TMB), R(TMB), F(TMB)	V, R, F, W, M		
EW/ECM	ALR-69 SYSTEM - RADAR HOMING & WARNING SCOPE THREAT DISPLAY UNIT	Will have Jan 82	Yes - Generic Sim.	None available	Yes	Yes - available	NONE AVAILABLE	
	AUTOMATED ECM - THREAT IDENTIFICATION & JAM	None - can provide 2 months' ARO	Yes		None now available	None now - could provide generic		
	ECM PODS - JAMMERS - FLARE - CHAFF		None - could provide now					

Advanced Simulator for Pilot Training ASPT	Crew Station Design Facility CSDF	Martin Marietta Orlando FL	Air Force (AFWAL) Flight Dynamics Lab FDL	McDonnell Douglas Corp St Louis MO	North American Rockwell Columbus OH		
None currently available - plan to modify B-52 WST DRLMS for fighter radar simulation Cost & schedule unknown.	F-111 analog land-mass available Plan to use B-52 WST DRLMS for fighter radar Cost & schedule unknown.	None available None planned	F-111 analog land-mass available Plan to use B-52 WST DRLMS for fighter radar	Four terrain model board systems available - 2 - 512 x 300 NM 2 - 80 x 80 NM	NONE AVAILABLE	RADAR IMAGE SIMULATION CAPABILITY DESCRIPTION	RADAR SIMULATION
Yes	Could do		None available	Yes		MOVING TARGET INDICATORS	
Could use ASPT image gen for high resolution radar	Can provide using TMB			Yes - TMB		SYNTHETIC APERTURE SIMULATION (SAR)	
	None			Yes - TMB		ADVANCED RADAR SIMULATION (64:1)	
Can provide two months' ARO	M-Yes, A - Aug 82	Yes		Yes		TERRAIN FOLLOWING MANUAL AUTO	
	M-Yes, A - 3 mo ARO	Yes				TERRAIN AVOIDANCE MANUAL AUTO	
N, V, F using DRLMS	N, V, F, W-graphics correlation only	All-graphics only		Yes		CORRELATION TO NAV, VISUAL, FLIR, MOVING MAP, WEAPONS	
Would use visual CIG system ASPT or F-111 CIG systems	Dual moving belt terrain models Processed video	Terrain model board Processed video	Terrain model board Processed video	Terrain model boards Processed video (multiple)	Two terrain model boards	IMAGE GENERATION SYSTEM AVAILABLE	FORWARD LOOKING INFRARED - FLIR
0 - 360°	0 - 60°	Variable 1° to 50°	36 x 48°	Variable ½° to 30°	Variable	FIELD OF VIEW AVAILABLE	
400 x 400 NM	200 x 200 NM 80 x 80 NM	9 x 18 NM	12 x 37 NM	30 x 50 NM 3 x 6 NM	30 x 50 NM 3 x 10 NM	GAMING AREA AVAILABLE	
On ground - up	150 ft - 4 K ft	250 ft - 2000 ft	100 ft - 20 K ft	200 ft - 20 K ft	100 ft minimum	ALTITUDE RANGE	
6 arc min - 2500 edges	Unknown	Unknown	Unknown	Unknown	Unknown	FEATURE/DETAIL RESOLUTION	
Unknown - Do have FLIR model algorithm	Unknown Video processed	Unknown Video processed	Unknown Video processed	Unknown - optical filtering Video processing	Unknown	FLIR SIMULATION FIDELITY	
Yes	Yes	Yes	Yes	Yes	No LANTIRN Simulation performed	SNAP LOOK CAPABILITY	
Yes	Yes	Yes	Yes	Yes		IMAGE SLEW CAPABILITY	
Yes - Up to 7	No	No	Video overlay	No		MOVING TARGET GENERATION CAPABILITY	
Yes	Yes	No	Can provide 6 months ARO	Yes		MOVING TARGET INDICATOR	
L, M, P	L, M	L, M		P	GBU-15 only	SIMULATION EXPERIENCE - LANTIRN, MAVERICK, PAVE TACK	
I, V, R	N	N, V, W	V	N, V, R, W, M		CORRELATION TO: NAV, VISUAL, RADAR, MOVING MAP, WEAPONS	

Advanced Simulator for Pilot Training ASPT	Crew Station Design Facility CSDF	Martin Marietta Orlando FL	Air Force (AFWAL) Flight Dynamics Lab FDL	McDonnell Douglas Corp St. Louis MO	North American Rockwell Columbus OH	VISUAL
CIG ASPT System	1) Dual terrain model boards 2) Night Visual System (NVS)	Dual probe terrain model board	Terrain model boards Dual scale	Model boards VITAL IV	Model boards as above	IMAGE GENERATION SYSTEM
Can use HUD	Must use real HUD	None			As above	FLIR HUD/OPTICAL IMAGE INTEGRATION
Variable - 360°	60°	Up to 50°	36° x 48°	360°		FOV
0 - ∞	0 - 20 K ft	250 ft - 2000 ft	100 - 20 K ft	20 ft - 18 K ft		ALTITUDE RANGE
400 x 400 NM	200 x 200 NM 80 x 80 NM	9 mi x 18 mi	12 x 37 NM	30 x 50 NM		GAMING AREA
6 arc minutes	Unknown	Unknown	3 arc minutes	Unknown	Unknown	FEATURE RESOLUTION
Yes	Yes	None	Yes	Yes	No	NIGHT CULTURE
Yes	Yes	None	No	No	No	NIGHT GROUND TARGETS
Yes	No, will have Aug 1982	None	No	Yes	No	NIGHT AIR TARGETS
CRT Mosaic	WAC Window	50° in-line collimated	Dome	Helmet Mounted Display & WAC window	None	DISPLAYS AVAILABLE
N, F, R, W	N, F	N, F, W	N, V	N, F, R, W, M		CORRELATION TO NAV, FLIR, RADAR, MOVING MAP, WEAPONS

APPENDIX B

OVERVIEW OF THE AIR FORCE AMRL PROGRAM IN WORKLOAD ASSESSMENT

ROBERT D. O'DONNELL, COL, USAF
AFAMRL/HEG

There is increasing awareness in the Department of Defense community that human capabilities have become the limiting factor in the performance of many systems. It is currently popular to express this through an increased concern with the workload which the system is imposing on the operator. Virtually every new aircraft system in use or in development contains avionics which are so sophisticated that they permit unparalleled performance. However, this performance frequently comes at the cost of higher operator requirements for information processing, decision making, memory, alertness, and precision. Further, as system performance becomes more sophisticated, the consequences or momentary lapses of attention and subsequent error become critical. Systems have developed to the point where it is virtually axiomatic to state that any error is a catastrophic error.

Recognizing this, the Air Force Aerospace Medical Research Laboratory and the USAF School of Aeospace Medicine have entered into a joint program to explore metrics which can assess an operator's performance, particularly in those situations in which the load imposed by the above types of factors can be manipulated.

To achieve these ends, the Workload and Ergonomics Branch of the Aerospace Medical Research Laboratory was established in July of 1979. Broadly, the mandate of this branch is to develop and implement standard techniques to validly measure the workload imposed by the aircraft system. In this definition, emphasis is placed on several terms. The mission of the branch is both "to develop and implement" techniques. As such, the branch has both basic and applied research goals. It is neither exclusively dedicated to the isolation of new workload measurement techniques, nor is it exclusively dedicated to the evaluation and adaptation of existing techniques to Air Force problems. Both goals are to be found in the same branch.

A second critical aspect of the program is implied by the word "validly" in the branch mandate. Validation of techniques, whether new or traditional, is a critical role of the branch. Any procedure recommended for use in the Air Force, whether in the laboratory or field will require extensive validation against criteria of mission success, with clearly defined criterion measures. For this reason, any metric developed within the context of the workload assessment program will receive extensive field test as part of the evaluation procedures.

As might be inferred from the above, a critical portion of the mandate involves identification of the operationally meaningful tasks being performed by the individual. Although it is necessary and scientifically pleasing to discuss conceptual definitions of workload, for purposes of providing answers to pressing workload questions in an operational environment such definitions are not productive. What the system designer or field commander wants to know is not whether a certain reserve capacity has been used or not, but simply "can the operator perform this mission under these conditions?" To answer this question, it is essential that an integral part of the workload program should be devoted to defining what the "missions" are. Therefore, the objective implies an active program to develop the means to describe the various missions being performed by the Air Force.

In light of these goals, a program with three major thrust areas was developed. The first thrust area involves "mission description". This is designed to provide the criterion measures against which any workload assessment technique will be evaluated. It also provides the final vehicle for predication of workload effects on mission effectiveness. The second major thrust involves "metric development". This encompasses the efforts to evolve new ways to assess workload as well as the evaluation of traditional techniques. Included in this thrust are the validation efforts required to determine the utility of proposed metrics. The final thrust area involves the development of hardware and procedures to permit, ultimately, standardization of the metrics developed above.

Associated with each of these major thrust areas is a schedule and a set of goals to be achieved within given time frames. The remainder of this paper will detail these goals and the target time frames identified for each period.

Mission Description

As noted above, the ultimate goal of a pragmatic workload assessment program is to define the effects of the required operator level of activity on the effectiveness of a mission. "Mission" may be viewed in a very narrow sense, encompassing only a specific behavior (e.g., can the operator make a particular radio frquency change at this point in the mission), or may be viewed in long term sense (e.g., will the pilot of a particular system be able to fly night attack missions for several months without catastropic error). In any case, the first requirement for answering such questions is to have a clear, and vali description of what the operator is expected to do. A major premise of the Workload Assessment program is that such questions should be specified as completely as possible. To that end, specific attempts are be'ng made to improve the quality of mission descriptions as they apply to workload questions.

WORKLOAD PLAN OBJECTIVES

Mission Description

0 - 2 years	2 - 6 years	7 - 10 years
o Identify "Choke Points	o Mission/Task Analyses	o Mission/Task Models
o Develop Criterion Measures	o Retrievable Data Bases	

The above figure presents the general picture of how the Workload Assessment program will approach such an issue. In the long term, the ultimate solution lies in the development of extensive mission/task models which can be computerized, and which will permit the manipulation of multiple variables, including workload, within a scenario. The SAINT model developed through AFARML by Pritsker and others, and the Human Operator Simulator (HOS) model developed under the auspices of NADC, at NASA, are preliminary examples. Emphasis should be given to continued development of such modeling so that, in the seven to ten year frame, these tools will be available for use. AFAMRL is therefore encouraging research funding agencies to support effort along these lines.

In the mid-term, during the period from two to six years, considerable effort must be devoted to the improvement of task analysis methodology. For various purposes, task analyses are now carried out quite differently. Depending on the goal of the analysis and the orientation of the analyst, task units may be as large as entire functional categories, or as small as individual motor behaviors or components of a decision task. There is some effort being carried out at the present time within the Human Factors Technical Advisory Group of the tri-services to standardize such task analysis techniques. If task analyses are to become the input vehicle for computer modeling of workload, researchers should become involved in influencing the way in which such task analyses are done. The level of granularity for such analyses must be tailored to the kinds of metrics being developed in the workload assessment community if the two are ever to contribute mutually. For this reason, it is desirable for researchers to become involved in task analysis description and particularly to encourage those who are involved in research in the operational environment to assure that task analysis methodology adequately reflects the way missions are performed, rather than becoming exercises in academic taxonomy.

For the short run, in the next two years, there is little hope of developing adequate task analyses across a broad range of complex real missions. We will be fortunate if we can identify, within the context of a few well defined missions, those points at which the pilot is clearly overloaded. In this way, high workload "choke points" can be pinpointed for further study and remedial action. After surveying the various techniques available to achieve this goal, the AFAMRL program has focused in on three particular types of approach to identify these workload "choke points".

Accident data are being surveyed to determine where, in particular missions with particular aircraft, accidents have occurred which could be attributed to overload. Hopefully, if there are distinctively weak spots in particular aircraft doing a specific maneuver, or under a combination of variables, these will become evident from such an analysis. The School of Aerospace Medicine is carrying out an extensive survey of accident data and AFAMRL is utilizing this information in their analysis.

Direct observation of various operational techniques is the second general approach being explored to identify workload choke points. Some Air Force organizations now use techniques for semi-automatically quantifying observations on mission activities (e.g., the "Data-Mite" and other types of automated clip board procedures). These procedures are of maximum utility only when the mission being observed is narrowly constrained with respect to the options open to the operator. Thus, missile launch sequences and other such well-defined missions are appropriate for such observations. Aircraft missions which afford the pilot a great deal of flexibility in the modes of achievement do not lend themselves well to such direct observation since virtually every type of mission would have to be observed.

Over the short term, it has become clear that the best hope for obtaining adequate descriptions of mission "choke points" lies in <u>subjective measures and interview techniques</u>. The value of expert opinion and the inputs from those who have actually operated the system can never be ignored. In practice, this usually is what determines system composition anyway. An attempt should therefore be made to standardize these techniques, and we have embarked on a program to study such techniques using the A-10 and F-16 aircraft as our model. Interviews of pilots from these systems have been carried out, using a structured interview technique. The pilot is first asked to describe all of the major parameters of a particular type of mission, such as airspeed, altitude, radio communications, etc. After laying out the entire mission, the pilot is asked to review each major segment, and to identify those in which the workload is considered to be high. The interviewer then proceeds to request specific task information within these segments. For each task identified by the pilot, the interviewer seeks information

about the input information, decisions, and behavioral action required. Once this is done for each task within a segment, the interviewer then goes to each aspect of the task (e.g., the decisions required) and obtains further information concerning the factors involved. In this way, the interviewer is able to carry the granuality of the survey as deep as necessary for any given purpose. In the current study, each interview lasted approximately three hours. The output of this procedure will define those aspects of the mission which are of high interest to workload assessment, as well as identify the "choke points" in the mission. Further, since the pilots themselves have generated the definition of the problem it is possible to question them concerning the nature of any "fix for the problem". This methodology has received favorable response from the operational community. It is expected that for the short term, this procedure will prove to be the best technique for identifying workload problems in Air Force missions.

Metric Development

The area of metric development for workload assessment is, of course, the crux of the problem. Identifying where workload constitutes a problem is only a first step. Intelligent decisions and remediation will require quantification of the workload involved. In the extreme, it is necessary no only to identify where workload is a problem, but to survey even proposed systems in order to determine whether or not the system can be operated from a workload viewpoint. In other words, it is desirable to "person-rate" every proposed system with respect to workload before the system is even accepted for production. The ultimate goal of a metric program should therefore be to develop detailed standards for such person-rating. As shown below, the goal of the AFAMRL program is to develop such standards, including specific tests that would be mandated.

WORKLOAD PLAN OBJECTIVES

METRIC DEVELOPMENT

o Standard Techniques -- Subjective -- Behavioral -- Neuropshchological/ Physiological	o Refined Test Battery	o Detailed Standards
0 - 2 yrs	2 - 6 yrs	7 - 10 yrs

To reach this goal, extreme care must be used in the development and validation of the tests. Such development, therefore is an iterative process which, in the mid-term, will involve development, test and refinement of many kinds of assessment procedures. The program therefore foresees the appearance of a series of "test batteries" which incorporate increasingly sophisticated measurement techniques, and which are constantly refined until enough confidence is generated to require these procedures for workload evaluation.

For the short term, researchers have generally concluded that no single currently available approach to workload assessment will prove adequate. Rather, a synthesis of subjective, behavioral/performance, and neurophychological/physiological measures offers the best hope for yielding useful measures in the near term. The program therefore, has initiated efforts along each of these dimensions.

In the area of <u>subjective metrics</u> (as opposed to subjective evaluation of mission scenarios), major emphasis is being given to interview and rating techniques over the near term. The USAF School of Aerospace Medicine has used such subjective evaluations, in the form of rating cards and interviews, for a number of years to assess fatigue, workload, etc. Of particular recent interest are efforts by Sheridan and others to refine the "Cooper-Harper" type of subjective rating so that it becomes specifically applicable to workload. In addition, serious attention is being given to the multi-attribute model as it has been applied to workload assessment through the mechanism of conjoint analysis. These efforts, under contract with the Navy, appear to offer an existing technique for quantifying the various subjective estimates currently being gathered..

The development of <u>behavioral metrics</u> is specifically being carried out at Wright-Patterson Air Force Base. For a number of years, AFAMRL has been engaged in evaluating the utility of secondary tasks, used both as loading tasks and as direct measures of primary task workload. Extensive work has been done on the use of tracking tasks, in all of their various forms, as secondary tasks. In addition, considerable effort has been devoted to looking at the Sternberg task as a secondary task measure of cognitive workload. These efforts have resulted in the development of a "workload assessment device" which is now incorporated in an NT-33 aircraft flying at Patuxent River, Maryland.

There is concern however, about the degree of intrusiveness of secondary tasks. In addition to well known scientific objections to such tasks, and problems with implementing them, the operator acceptance of secondary measures in operational environments is not notoriously high. The AFAMRL program therefore, has emphasized the development of "minimum intrusion" tasks. To this end, the investigation of the Michon Tapping Task has been encouraged. This task appears to produce little interference with the primary task. Other such minimum intrusion tasks should be developed as candidates for secondary task assessment of workload.

A candidate for such an approach is currently being developed within this program. In this technique, the primary task of interest (in this case, the flying task) is taken as the basic unit. Within that primary task, a subtask is isolated and quantified with respect to workload. Once such quantification has been done,then this subtask can be returned into the primary task, or "embedded" within it. In this way, a quantified secondary task can be added to a primary task of interest, and the net result is that the operator does not perceive the primary task as being any different. Thus, the intrusion into the primary task by the secondary task is minimized to that necessary manipulation of the secondary required to obtain quantification.

As an example of this, the communications tasks associated with real flying scenarios in the A-10 aircraft have been isolated. Operational pilots described several realistic communications scenarios associated with particular kinds of missions. These scenarios were then studied by themselves, and the workload associated with each scenario was quantified by three separate techniques. An information theoretic analysis was performed on each communication element of the scenario. In addition, a paired comparison of workload associated with each communication element was performed by over thirty Air Force pilots. Finally, a joint measure of workload incorporating both the information theoretic and the paired comparison results was developed and validated against the judgment of another set of pilots. In this way, a good ordinal classification of the workload associated with the communications involved in a real mission has been developed. The next step, currently being carried out, is to take these communications tasks, and employ them as secondary tasks with primary tasks of known workload. Results of this experiment will indicate whether or not the communication task is affecting and affected by the primary task in the same way as traditional secondary tasks might be expected to react. If this approach appears feasible after initial test, then larger scale simulations will be used, and ultimately the communications workload approach could be used in field tests. The advantages of this approach obviously are increased acceptance of the procedure, high face validity, and a significant decrease in the apparent intrusiveness of the measure. If, while gaining these advantages, none of the traditional advantages of secondary measures are lost, the approach should prove valuable to a range of applications.

Another new approach to analyzing workload is being considered. It has been noted that an increase in workload on the individual frequently results, not in a change in performance level, but rather in a change in the adaptive strategy used to achieve that performance level. Thus, as workload is increased, the individual strives to maintain performance by changing the criteria, the strategy, or the unnecessary fine detail of the performance approach. It may be that by studying strategy directly

one may obtain a more sensitive index of workload than by looking at the task performance. A program to assess such approaches to strategy analysis has therefore been initiated. The primary task performance of the individual will be analyzed over a wide range of performance variables, and interactive aspects (e.g., improvement in one variable correlated with decrement in another) will be analyzed for consistent and meaningful patterns of strategy within the individual. It is hoped that this will provide some indication of the load being perceived by the operator. If these preliminary tests show promise, further development will be pursued.

Neuropsychological/Physiological Metrics

Historically, physiological measurement has been used in field situations principally to assess the effects of long-term stress on the individual. Biochemical measures such as Catacholamine excretion have been used to indicate the level of stress after some relatively long term performance (although recent evidence indicates that such measures may be useful in short term stress conditions). For assessment of short term stress and some factors associated with moment-to-moment performance, electrophysiological measures have been used extensively. Such techniques as the electromyogram, the electrooculogram, the electrocardiogram, and the electroencephalogram have been used with varying degrees of success. However, these have been primarily used in laboratory settings. The incidence of field application is rather limited.

AFAMRL began to look at a variety of electrophysiological measures soon after 1970. The measure which proved to be of considerable value and which has received the most emphasis has been the cortical evoked response and other event related potentials obtained from the electroencephalogram. A large development program, both in-house and on-contract with universities has been carried out. It was realized that while the technology for electrophysiological recording is not in any sense mature, the progress made over the decade of the 70's had revealed ways to use electrophysiological recording to assess workload in the field. At this point, it was decided to take what was currently available and "harden" it into standardized ways to assess workload electrophysiologically. This approach was taken even though it was clear that some procedures identified and implemented at this early stage may ultimately prove unsatisfactory. The production of a standardized set of neuropsychological tests for workload assessment is probably premature in any ultimate sense, but absolutely necessary at this point and time. Without it, there will be ten years of further discussion, with no real further progress toward application. With a concrete device to test, validate, and revise, it is possible that, in ten years, significant progress toward standardizing the neuropsychological assessment of workload may be made.

With this rational in mind, AFAMRL has committed itself to the development of a neuropsychological test battery for workload assessment. Many individuals actively participated in the conceptual phase of this development. Thirty-five individual experiments were performed to test out various aspects of the tests that comprise the test battery. Results from these experiments have been published in various sources, and will not be individually cited.

An extensive field validation effort will be carried out to define the uses, limitations, and possible expansions of the test battery. Ultimately, a revised version is anticipated in the 1985-86 time frame, and at that time, the battery will be integrated with the psychological and subjective techniques developed under this program. Hopefully, such an integrated battery will provide the foundation for further refinements and improvements, so that, by the late 1980's some degree of standardization in workload assessment metrics may be achieved.

APPENDIX C

CONJOINT MEASUREMENTS AND DELTA SCALE PROCEDURES

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Subjective opinion techniques for assessment of operator workload have received increased support in the recent literature as a potentially important measurement technique. One investigator (Sheridan, 1980) has proposed that mental workload should be defined as a person's subjective experience of his or her own cognitive effort. Johannsen, Moray, Pew, Rasmussen, Sanders, and Wickens (1979) state that a complete and adequate theory of operator workload will be one of two things: the end product of a total theory of human performance or alternately, a description of how an operator feels when performing a task. Jonannsen et al (1979) indicate that in spite of the difficulties with use of rating scales, they should be regarded as central to any investigation of workload. In a similar vein, Gartner and Murphy (1976) indicate that when experimental conceptualizations of workload are accepted, the operator's direct perception or estimation of his feelings, exertion, or condition may provide the most sensitive and reliable indicators of workload.

Subjective assessment techniques have been quite frequently employed a an adjunct to performance-based workload assessment techniques in a wide variety of situations. In many instances, individual subjective assessment procedures have been developed for a specific application and therefore have not typically been subjected to extensive validation which could be used to recommend their generalized application in a wide variety of situations. Also, there is little evidence in the current literature of workload rating scales that they have been based on psychometric theory (Reference 1).

One measurement technique which is potentially applicable to the development of suitable workload rating scales is the technique of conjoint measurement (References 6, 7, and 10). Additive conjoint measurement and delta scaling procedures (Reference 1) hve been applied in development of rating scales for use in assessment of the workload associated with the F-18 (References 3 and 8) and the A-7E (Reference 3) aircraft.

Basically, conjoint measurement and associated scaling procedures allow an investigator to obtain separate ordinal ratings of two or three dimensions and to combine these ratings in such a manner so that a one-dimensional scale with interval properties can be created. One advantage of conjoint measurement over univariate scale techniques is the fact that the univariate techniques make certain assumptions about the underlying distribution of rating scores in order to derive a scale with interval properties. The conjoint measurement technique minimizes the need to make such assumptions, and depends primarily on the ordering relationship among cells in a matrix which is derived from two or more ordinal scales.

In their application of conjoint measurement and delta scaling procedures to the F-18, (Reference 3) obtained ordinal ratings of pilot workload and system technical effectiveness on separate four point scales. The four-point ordinal scales were subsequently combined in a single interval scale which represented an overall measure of F-18 system operability on portions of the mission which had been rated. In a subsequent effort, the system evaluation procedures developed for the F-18 were further modified in an application to the A-7E aircraft (Reference 2). Some modifications were introduced into the descriptors for the ordinal workload and technical effectiveness scales, and an interval scale of A-7 system operability was produced.

Although previous applications of the conjoint measurement and delta scaling techniques have utilized operator workload and system technical effectiveness scales in order to derive a single interval scale of system operability, there is no theoretical reason to restrict applications to this particular format. Workload itself has been characterized as a multidimensional construct in several recent statements (Reference 5) and includes such elements as operator effort, time pressure, information processing load, etc. One viable avenue for future applications of conjoint measurement and delta scaling procedures could be to develop two or three ordinal rating scales which represent important elements of the workload construct and to combine the ratings from these scales into a single interval scale which would represent the subjective workload associated with a particular mission or mission segment or task. Ratings on this interval scale could then be correlated with other performance-based and physiological measures in order to investigate the relative sensitivity of the various measures to changes in levels of mission workload.

The advantages of such an approach would include the potential capability to derive an overall interval workload scale from two or three relatively simple ordinal scales. The ordinal scales should be brief enough to permit relatively non-intrusive implementation in a variety of situations, and the resulting interval scale is derived with a minimum number of assumptions. In addition to its great potential practical utility, the approach has considerable theoretical appeal because of current statements which characterize workload as a multi-dimensional construct, and could be used as a vehicle to provide some evaluation of the relative contributions of various proposed elements of workload to the overall subjective workload experienced by the operator.*

* Author's Note: The above discussion serves as a precursor to a more up-to-date and comprehensive treatment of subjective, as well as performance and physiologically based indices of workload (also provided by Dr. F. Thomas Eggemeier) included in Vol. I of this Technical Report (see page 33-42).

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APPENDIX D

PAST STUDIES PERFORMED IN SUPPORT OF THE NIGHT ATTACK MISSION

The following pages summarize previous efforts to evaluate a variety of night attack equipment configurations and resulting capabilities.

SIMULATION TECHNICAL REPORT
A-10A PRECISION ATTACK ENHANCEMENT (PAE)
Part II, EVALUATION OF FIVE FULL MISSION CONFIGURATIONS
ASD-TR-77-30, PT II, JAN 1979

The principal test objectives of this Precision Attack Enhancement (PAE) simulation was to determine the performance effectiveness achievable with several candidate avionics configurations when employed in a low speed, maneuverable, single-seat aircraft on nighttime tactical air to ground missions. Five sensor/display configurations (four single sensor and one dual) were evaluated in this full mission simulation.

Configuration 1 uses a 20 degree FOV (with a 3 x 4 aspect ratio) simulated FLIR sensor for NAV/TA. The sensor image is displayed on the HUD at unity magnification. The sensor axis is stabilized about a forward, fixed LOS and is depressed a nominal 6 degrees relative to the aircraft centerline. The Laser ranger axis is collocated with the sensor axis. In order to redirect the FLIR sensor LOS with respect to the general terrain or a specific point, the pilot must alter and control the aircraft heading to accomplish a desired change in sensor/laser aiming (such as achieving updated laser range for an INS update).

Configuration 2 is similar in all respects to Configuration 1 except that the FLIR sensor and laser ranger are gimbaled in order to accomplish a "Snap Look" away from the nominal forward-looking LOS direction. This feature is intended primarily for TA flight where it may be of considerable advantage to look in the direction of an intended maneuver prior to committing the aircraft along this path (effectively extending the sensor FOR--field of regard).

Configuration 3 is similar to Configuration 2 except that the gimbaled FLIR sensor and collocated laser ranger are capable of being commanded over a considerably larger FOR angle and the LOS movement can be controlled in a continuous manner.

Configuration 4. The pilot's only useful visual contact with the ground in this mechanization is via the HDD.* The gimbaled FLIR sensor and laser are identical to those in Configuration 3 and the LOS control modes also are the same. A standard A-10 non-imaging HUD, displaying symbology without sensor video, is utilized in flight and navigation functions. The pilot must use the HDD for all mission functions which require a visual display of the terrain. This includes all previously defined mission sub-tasks except threat countering.

*As with the other configurations, it is assumed that the defined "dark night" condition precludes effective direct visual contact with the terrain through the HUD optical combiner.

Configuration 5. This system uses major elements from Configuration 2 for the HUD portion (except that no narrow FOV is available). The HDD portion consists of a high resolution, two FOV gimbaled FLIR tracking sensor plus a collocated laser range/illuminator. This subsystem, which represents an equipment pod in the real world, has a lower hemispherical FOR capability with the sensor LOS continuously controlled by pilot rate-type slew commands or by automatic LOS cueing commands from the INS. Video from the HDD sensor is fed to tracker electronics providing both area contrast tracking and point contrast tracking which is switch-selectable by the pilot.

The HUD subsystem, incorporating Snap Look capability, is used for the NAV/TA functions, for gross target area detection, and for weapon delivery in the Gun and Bomb modes. With the HDD sensor LOS slaved to the INS-computer LOS (INS cue mode) target acquisition and acquisition of any identifiable INS point normally is completed using the HDD. The pilot switches from the CUE to TRACK mode to accomplish precision sensor LOS alignment on the target via the slew controller. This same procedure is followed in the case of INS updates.

The point tracking capability is required when sustained, precision LOS alignment is required on the target. The laser weapon delivery mode requires this capability to permit the pilot to concentrate on head-up flying tasks while the automatic tracker maintains an accurate laser illuminator LOS on the target.

The majority of pilot subjects believe that low level, nighttime tactical air-to-ground missions are feasible using an optimized PAE avionics system in a maneuverable slow speed aircraft.

The need for the following PAE subsystems has been verified:

a. Inertial Navigation System (INS)

b. Radar Altimeter

c. Imaging head-up display (HUD)

d. Raster type symbology generator

e. Laser ranger (and illuminator if laser guided weapons are employed).

Dual sensor Configuration 5 is the strong preference as the candidate which will achieve highest mission effectiveness. Both the NAV and target acquisition/tracking sensors should be gimbaled and the latter should have dual FOV capability.

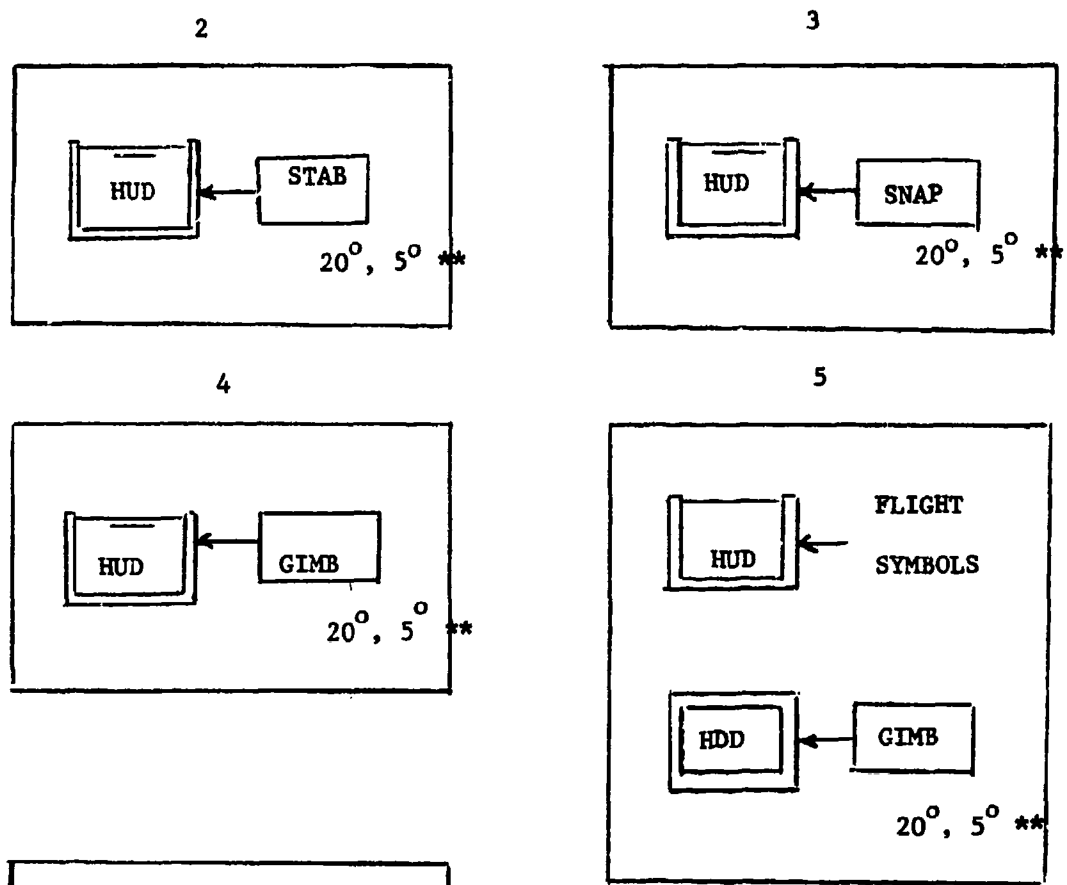
Pilot learning effects were generally in evidence throughout the formal test phase. This indicates the need for more training if performance plateaus are to be reached prior to data measurements.

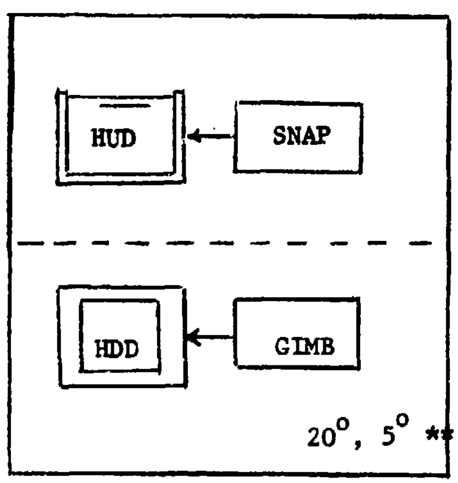
The lower mission success rates associated with Imaging Infrared (IIR) MAVERICK deliveries compared with gun and bomb deliveries reflect the highest workload in this weapon mode and the corresponding need for more pilot training/experience to obtain a more accurate estimate of potential performance.

Austere single sensor Configuration 4 was determined to be unacceptable based both on objective and subjective performance measures.

This experimental program did not produce sufficient objectively-based data to permit a statistical ranking of the remaining four candidate Configurations 1, 2, 3, and 5. There is a strong evidence however, that more training per configuration and especially on dual sensor Configuration 5, would produce significant performance differences. This leads to the conclusion that additional formal testing is required to establish objectively-measured performance differences between these configurations. This test should be preceded by an engineering oriented optimization phase to incorporate important configuration improvements stemming from the present experimental program.

The subjective data and unrecorded pilot discussions overwhelmingly show that if they were asked to fly a similar mission under real (versus simulated) condition, they would prefer to have an optimized dual sensor configuration. Pilot comments indicate that the high resolution, high contrast, stabilized video on the HDD, the automatic target cueing and tracking features provided by the target acquisition sensor and the head-up NAV sensor video on the HUD, with some side-look capability, constitute critical features of a suitable dual sensor system.





LEGEND

HUD- IMAGING HEAD-UP DISPLAY
HDD- HEAD DOWN DISPLAY
STAB- STABILIZED FLIR
SNAP- SNAP-LOOKED GIMBALED FLIR
GIMB- SLEWABLE GIMBALED FLIR

**MOMENTARY FOV

NOTE: ALL CONFIGURATIONS HAVE INS CUEING
ALL FOVs ARE DIAGONAL DIMENSIONS

Sensor/Display configurations

SINGLE SEAT ATTACK-NIGHT SIMULATION STUDY
PHASE I - PART I TARGET DETECTION/CLASSIFICATION JUNE 1977
FINAL REPORT ASD-TR-77-30, PART I

SUMMARY -

The purpose of the Single Seat Attack-Night (SSA-N) program is to determine the feasibility and requirements for performing air-to-surface strike missions with single seat aircraft. One of the main issues of the program is the consideration of pilot workload. As acquisition aids are added to the aircraft the ability of the pilot to control these aids, utilize the additional information, and continue to perform the normal piloting functions must be determined. This issue becomes more critical as the threat/survival factor requires mission profiles utilizing higher airspeeds and lower altitudes.

The primary purpose of the simulation study was to rank the performance of candidate system configurations with the man in he loop on the basis of controlled simulation testing and supporting engineering evaluation and analysis.

This effort involved the use of eight candidate system configurations as defined in the attached table. The basic experiment utilized USAF A-7 pilots as subjects (single seat tests) and was repeated using USAF F-4 WSOs (backseaters) and a simulated pilot (two seat tests). The primary purpose of the two seat tests was to determine if the same performance ranking of configurations held for the backseaters when compared with the pilots who had the additional task loading of flying the aircraft.

Configuration that employed both body fixed and gimbled sensors were preferred by the pilots and yielded the best target detection/ classification and flight control performance. Configurations that employed a body fixed sensor only yielded the poorest performance and were given low ranks by the pilots. Configuration 6 was the clear preference of the pilots and also produced the most consistently high performance for both target detection/classification and flight control. Configurations 3, 7, and 8 yielded high target detection/classification and flight control performance in several of the test situations and were ranked well by the pilots. As a minimum, Configuration 3 and a modification of Configuration 8 (based on some characteristics of Configuration 7) should be included in future studies along with Configuration 6.

The backseaters clearly preferred Configuration 3 and clearly disliked Configuration 2 (body fixed sensor). Target detection/classification performance achieved with these configurations followed the same ranking order. There was no indication, either subjectively or by performance, that the addition of a body fixed sensor image along with the gimbaled sensor was of any value to the backseaters. This does not necessarily suggest that a body fixed sensor would not be advantageous for the pilot of a two man crew. The experiment did not address this condition.

SENSOR/DISPLAY CONFIGURATIONS TESTED

Configuration	Sensor/ Display	Description
1	FS/HUD	Body fixed sensor (FS) with selectable FOVs imaged on head-up display (HUD) along with flight and cueing symbology.
2	FS/HMD	Body fixed sensor with selectable FOVs imaged on helmet-mounted display along with flight and cueing symbology.
3	GS/HDD	Gimbaled sensor (GS) with selectable FOVs imaged on head-down display (HDD) with cueing and attitude symbology. Flight and cueing symbology (but not sensor image) presented on head-up display.
4	FS/HUD	Gimbaled sensor with selectable FOVs imaged on head-up display along with flight and cueing symbology.
5	FS/HMS/D	Gimbaled sensor with selectable FOVs imaged on helmet-mounted sight/display (HMS/D) along with cueing and attitude symbology. Flight and cueing symbology (but no sensor image) presented on head-up display.
6	FS/HUD + GS/HDD	Gimbaled sensor with selectable FOVs imaged on head-down display along with cueing and attitude symbology. Body fixed (fixed FOV) sensor (unity magnification) imaged on head-up display along with flight and cueing symbology.
7	FS/HDD + FS/HMS/D	Gimbaled sensor with selectable FOVs imaged on helmet-mounted display along with cueing and attitude symbology. Body fixed (fixed FOV) sensor (unity magnification) imaged on head-down display along with flight and cueing symbology.
8	FS/HUD + GS/HMS/D	Gimbaled sensor with selectable FOVs imaged on helmet-mounted display along with cueing and attitude symbology. Body fixed (fixed FOV) sensor (unity magnification) imaged on head-up display along with flight and cueing symbology.

DT&E FLIGHT TEST OF THE F-111F PAVE TACK/GUIDED WEAPONS SYSTEM
TR ADTC-TR-79-19 APRIL 79

Although the F-111F aircraft has low-level penetration capability and precision radar; ordnance delivery is restricted to unguided weapons and laser guided weapons that use designation from either a ground laser or airborne laser in another aircraft. The addition of PAVE TACK/GUIDED WEAPONS to the aircraft is designed to provide a self-contained guided weapon delivery system as well as an improved conventional weapon delivery system. The guided weapon capability includes laser guided bombs, AGM-65 Maverick missiles and GBU-15 glide bombs.

A 105-mission flight test was conducted to collect sufficient engineering and operational data to support a Class V modification decision.

Although incorporation of the PAVE TACK/GUIDED WEAPONS modification has provided additional capability, it has expectedly resulted in a corresponding increase in switchology and greater time demands upon the aircrewmembers. The weapon system operator (WSO) is now responsible for the operation and monitoring of two sensors (attack radar and FLIR) in addition to procedures required for delivery of guided weapons. When performing acquisition and tracking tasks with the PAVE TACK sensor or GUIDED WEAPON, the WSO was almost totally dedicated to viewing video displays and to operating associated tuning functions. The aircraft commander therefore must assume more responsibility for many functions (electronic countermeasures operation, monitoring engine instruments and aircraft performance) that had formerly been shared by the aircrew.

Consideration of human factors was necessary during mission planning prior to flight. Ramification of target size, shape, temperature, and emissivity, as well as characteristics of surrounding terrain (such as elevation, temperature, presence of trees, and water) were important in determining expected FLIR and television (TV) seeker acquisition ranges. The crew was required to ascertain when to transition from radar to FLIR or TV seeker acquisition. Excessive attention to FLIR or guided weapon video displays, prior to ranges at which acquisition was physically possible, was counter productive and prevented accomplishment of more immediate, essential tasks.

PAVE TACK NIGHT ATTACK SYSTEM/F-4 IOT&E FINAL REPORT
TAC PROJECT 76C-020T NOV 79

PAVE TACK is an integrated sensor system developed as a Class V modification to the F-4E/ARN-101 digital avionics aircraft.

The PAVE TACK pod is a non-jettisonable pod carried on the centerline station of the F-4E aircraft. The pod sightline can be slewed through the lower hemisphere during flight. The PAVE TACK system is installed in an aerodynamic pod with aft mounted optics. The forward section of the pod contains power supplies, environmental control unit (ECU), video tape rerder (VTR), and other associated control electronics. The aft section of the pod contains a rotatable turret with the FLIR receiver and optics; the laser ranger/designator transmitter, receiver, and optics; stabilized sight assembly; drive mechanism; gimbals, and the sensor window.

The PAVE TACK pod is designed to operate in five independent self-contained modes and one ARN-101 aided mode. These modes are forward, left and right acquire, terrain monitor, snow plow, and ARN-101 cue. After acquiring a target using one of the above modes, the pod can be put into manual track, and laser designation can begin.

Overall, the cockpit configuration of the test aircraft was deficient. The arrangement of control panels, control functions, the PAVE TACK control handle, and the Virtual Impage Display Unit (VIDU) controls were not optimized and did not lend themselves to effective or efficient system operation by the Weapons System Operators (WSOs). Operation of some of the controls caused interference with the control stick, cross handed operations, and inadvertent activation of other controls.

During the test program, WSOs had little opportunity to monitor aircraft position, altitude, heading and airspeed due to PAVE TACK system operation. The bulk of the navigational responsibility was assumed by the pilot. The WSO became more of a system manager/operator, less of a navigator, and less able to provide assistance and backup to the pilot.

It was recommended that follow-on operational test and evaluation programs evaluate distribution of workload between the front and rear cockpits.

APPENDIX E

HMDs - GENERAL CONSIDERATIONS FOR OPERATIONAL APPLICATIONS

DEAN F. KOCIAN

AFAMRL/HEA

A variety of critical parameters including size, weight, exit pupil, eye relief, field of view (FOV), collimation, distortion, image quality, ambient lighting considerations, etc., must be analyzed when considering HMDs for a particular application. However, it is possible to make some important subjective judgments on the probability of success for a given application based upon just a few of the operational requirements and display parameters that a complete analysis would consider. These can be limited to the following: (a) the ambient lighting conditions under which the HMD must perform; (b) whether or not see-through capability is required for the optical element(s) in front of the observer's eye; (c) the range of G acceleration over which the display must be used; (d) the required display FOV, and; (e) the type of imagery to be displayed and the resolution requirement for this imagery. The general guidelines which follow are based upon subjective and quantitative data derived from laboratory and flight test experience involving a wide range of applications and HMD designs, and are meant to serve only as a quick introduction to the area. For a more complete discussion, the interested reader should refer to the bibliography listed at the end of this appendix.

The primary consideration for a particular HMD design, is, of course, the application for which it will be used. The most important conditions that must be considered first are the resolution requirement and the ambient lighting conditions under which the HMD must function. These can effectively be divided into four combinations that represent a wide range of design difficulty. Table 1 depicts these four general combinations with the order of increasing design difficulty runing from top to bottom.

Table 1 - HMD Application Situation

Resolution Requirement	Ambient Lighting Conditions
graphics/symbology only	daylight viewing
graphics/symbology only	night viewing
high resolution imagery without symbology	night viewing
high resolution imagery without symbology	daylight viewing

The first combination (symbology only - daylight viewing) is to a considerable extent, the easiest to implement. The reasons for this are:

1. Symbology presentation only requires "one gray shade" above the background luminance to be easily visible whereas imagery requires far more shades of gray to produce reasonable quality imagery.

2. Since the HMD luminance for symbology can be relatively low compared to that required for imagery, the combiner transmission coefficient can be kept fairly high (low reflectance coating) and thus the luminance disparity with the HMD on or off is low.

3. Overlaying symbology on the real world scene is a compatible process and produces a reasonably integrated total scene, whereas HMD imagery tends to produce a result more like a double-exposed photograph. This effect can be minimized but the potential for operational problems is greater with imagery than with symbology.

4. The daylight presentation tends to "wash out" any ghost images and provides a better luminance belance between the two eyes than the night situation.

For applications that only require low resolution information or alpha-numeric symbology, current technology does exist to permit the design of a HMD that is free from major human factors problems and which can be operated in all normally encountered ambient brightness conditions (night to bright sunlight) throughout the range of G acceleration ordinarily experienced in tactical aircraft (-2.5 to +8.0). See-through capability is usually not a significant design issue and can also be provided without incurring important operational or human factor problems. For applications requiring high resolution, TV type presentations, the tradeoffs are more complex and the range of application more limited. For low ambient lighting conditions, experience seems to indicate that high resolution displays are usable; however, the larger FOV that is normally required as well as the heavier optical assembly needed to maintain image quality usually limits their use to a more restricted range of G acceleration. In addition, image quality considerations almost always dictate that the CRT image source remain on the helmet, further restricting operating conditions. For high resolution HDMs operated in high ambient brightness or daylight conditions, human factors problems such as binocular rivalry between the display's view of the outside world and the outside world as actually perceived become significant. See-through versions of such displays further increase the complexity of the human interface problem.

Some generalized statements about specific performance characteristics now possible with operational HDMS can also be made, however, the reader is cautioned that the capability exists to produce a significant variety of alternate HMD designs to satisfy a given application. With the technology available today or in the foreseeable future, it is extremely difficult to design a high resolution, monocular HMD for tactical aircraft with a diagonal FOV greater than approximately 40 degrees. If the normal 4:3 aspect ratio, rectangular format is desired, then the horizontal FOV is limited to about 30 degrees and the vertical FOV to about 23 degrees. Display systems which attain this level of performance can be interfaced to the standard Air Force helmet and used with reasonable comfort up to +Gz accelerations of 4.5. Above this acceleration level and for ejection, standard operating procedure assumes a quick disconnect helmet interface, which would allow the HMD to be stored in a convenient cockpit location. One other area that deserves special consideration is the quick disconnect feature for the CRT cable used for ejection situations when the CRT is still operating. While this problem has had considerable attention during past HMD design efforts and is largely solved, some difficulty may still be encountered for specific applications and required operating procedures. The weight penalty incurred, depending upon the specific optical design, for adding such performance to the helmet is usually about 400 grams. If lower resolution and smaller FOVs (maximum of about 20 degrees) are sufficient, then HMDs can be designed which remove the CRT from the helmet. A lightweight, rugged fibre-optical bundle with low bending resistance can be used to transmit the imagery to the helmet and a simplified optical system can be used to present the imagery directly on a parabolically shaped helmet visor. A HMD design of this type, also appears to encounter minimum interface problems if chemical defense hardware is added to the helmet. The weight penalty for the helmet is reduced to about 150 grams and ejection problems can be solved with a simple guillotining system for the fibre-optic bundle.

HMD performance has been given a recent boost, due to CRT performance improvements that have been accomplished as a result of unique programs like the VCASS (Visually Coupled Airborne Systems Simulator). During the past 18 months, CRTs with newly designed electron optics, high efficiency, computer-aided designed deflection yokes and dispenser cathodes which permit higher beam currents and longer tube life have been successfully demonstrated. In addition, a new, more rugged P53 phosphor (operating in the yellow-green portion of the visible spectrum) has been developed. This extremly hard phosphor permits small grain sizes with only a modest decrease in efficiency. These characteristics make possible higher resolution/brightness presentations while maintaining superior resistance to "burn-through", a problem sometimes encountered when the CRT electronics cannot compensate quickly enough for high beam current/low velocity spot motion operating conditions. These technology improvements taken together permit a spot size of 15 microns to be maintained for CRT faceplate luminance levels of several thousand Ft-Lamberts. A general projection can be made about the usable resolution

that might be obtained with this new CRT with the clarification that a final performance figure would be the result of a set of complex interrelated factors that are design specific. For the high resoution 40 degree FOV display described above, using appropriately designed optical bandpass filters for see-through capability, such performance translates into a display with a usable limiting resolution of about 2.5 arc minutes. For the smaller FOV, lower resolution display with fiber-optic link, limiting resolution rises to about 4.5 arc minutes. The performance stated above assumes some attentuation of the ambient light occurs and that ambient brightness conditions do not exceed luminance levels of 10,000 Ft-Lamberts. Total weight for this new CRT with a nominal length of unsupported cable is 130 grams. The use of solid-state display devices has been suggested as an alternative to CRTs, in order to eliminate some of the limitations (size, weight, etc) imposed on HMD designs. However, especially for high resolution applications, it will be at least 7-10 years before such displays attain resolution/brightness levels comparale to that of the CRT. In addition, for collimated, virtual image HMDs, the optical assembly, which contributes a significant portion of the total added helmet weight, will still be required.

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